THE COMBINED EFFECTS OF TEMPERATURE, BACKGROUND NOISE AND LIGHTING ON THE NON-PHYSICAL TASK PERFORMANCE OF UNIVERSITY STUDENTS

Laura Pronk BSc (Hons)

Submitted for the degree of Doctor of Philosophy

Heriot-Watt University

School of the Built Environment

February 2008

ABSTRACT

This thesis examines the effects of temperature, background noise and lighting on the mood and performance of university students through laboratory study. These variables are considered in the context of the various building regulations and requirements that educational spaces are subject to. Such results are useful for those involved in the design of educational spaces, acting as an extension to existing standards.

A preliminary study was conducted to examine the suitability of using a within-subjects design, the results of which demonstrate that between-subject methodologies can be more suitable. This finding was used to design a full factorial between-subject methodology.

Results showed that noise was the most important variable for mood, with increased sound pressure levels being associated with more negative mood description. Students did not have to find a background noise distressing in order for their mood to be affected by it. Lighting was found have different types of negative effects in both the dim and bright condition, where bright light interfered with language fluency, and dim lighting was associated with concentration errors. Temperature is influential to students' assessment of environment comfort.

Acknowledgements

The author sincerely thanks Dr Gillian Menzies for her guidance and support throughout the course of work. She would also like to thank Dr Fiona Grant and Prof Craik for helping her to plan the research and for their continuing moral support. Dr C Leishmann was infinitely patient in his help with the analysis of the results, for which the author is very grateful. All the staff and students of the School of the Built Environment were encouraging and supportive throughout. Thanks to the technical staff who helped refurbish and customise the environmental chamber. Many wholehearted thanks to the author's family and friends for their unfailing support and kindness over the course of study.

This research would not have possible without the kindness of the 150 individuals who agreed to volunteer an hour of their time. Special thanks are extended to each of them.

ACADEMIC REGISTRY
Research Thesis Submission

Name:	Laura Pronk		
School/PGI:	School of the Built Environment		
Version: *(i.e. First, Resubmission, Final)*	Temporary (First Submission) Bound Thesis	Degree Sought:	PhD

Declaration

In accordance with the appropriate regulations I hereby submit my thesis and I declare that:

1) the thesis embodies the results of my own work and has been composed by myself
2) where appropriate, I have made acknowledgement of the work of others and have made reference to work carried out in collaboration with other persons
3) the thesis is the correct version of the thesis for submission*.
4) my thesis for the award referred to, deposited in the Heriot-Watt University Library, should be made available for loan or photocopying, subject to such conditions as the Librarian may require
5) I understand that as a student of the University I am required to abide by the Regulations of the University and to conform to its discipline.

* *Please note that it is the responsibility of the candidate to ensure that the correct version of the thesis is submitted.*

Signature of Candidate:		Date:	5/6/08

Submission

Submitted By *(name in capitals)*:	Laura Pronk
Signature of Individual Submitting:	
Date Submitted:	5/6/08

For Completion in Academic Registry

Received in the Academic Registry by *(name in capitals)*:	CAROLINE COOKE		
1.1 Method of Submission *(Handed in to Academic Registry; posted through internal/external mail)*:	HANDED IN		
Signature:		Date:	5/6/08

Table of Contents

Table of Figures

List of Tables

List of Appendices

Chapter 1: Introduction

1.1 Introduction

Lecture theatres and classrooms are educational environments, providing space for a variety of teaching and learning activities to take place. These most often take the form of lectures, ranging in style from traditional formats, to modern multimedia presentations, to interactive sessions where students work in groups. Less often, but equally importantly, teaching spaces are used for work demanding higher levels of mental concentration from students, such as problem solving tasks in tutorials, or sitting examinations.

The environment provided in all classrooms or lecture theatres must legally comply with the Workplace (Health, Safety and Welfare) Regulations (1992). These regulations are non-prescriptive, only requiring that *"temperature in all workplaces inside buildings shall be reasonable"*, and that *"every workplace shall have suitable and sufficient lighting"*.

Noise, being potentially harmful, is addressed from a noise exposure perspective by the Control of Noise at Work Regulations (2005). Exposure is limited to a daily or weekly personal noise exposure of 87 dBA and a peak sound pressure of 140 dBC. Such high noise levels would never normally be encountered by students undertaking normal classroom activities.

To supplement these very basic requirements, school buildings are subject to a range of additional legislation in the form of School Premises Regulations , and the Department for Education and Skills (DfES) publications known as Building Bulletins. There is no equivalent set of publications for university buildings.

Building Bulletins give more detailed requirements for lighting, heating and cooling systems in classrooms, aimed at improving health, safety and comfort provisions. Lighting in classrooms must exceed a minimum requirement, designed to meet the visual needs of students and teacher (CIBSE 1991). The thermal climate in classrooms must fall within a range of temperature which is considered appropriate for the level of activity taking place in the space (Building Bulletin 87: 2003).

Noise is treated differently, due to recognition of its potential for affecting learning and performance. Upper limits are set for indoor ambient noise levels, and schools are required to be designed and built in ways which reduce noise levels in the classroom, so that concentration is maximised and distraction is minimised (Building Bulletin 93: 2003).

These examples demonstrate some basic differences between legislative requirements for school and university environments. Where universities are bound only by the fairly non-prescriptive safety laws, a higher quality standard is required for schools, through the Building Bulletin system. The acoustic requirements are notable for attempting to enhance concentration in the classroom, recognising that noise has effects beyond the physiological.

The field of environmental psychology has shown that variables such as lighting and temperature also have the potential to affect non-physical factors which impact on performance, such as mood and concentration. This experimental evidence suggests that temperature, lighting and noise can have these effects at levels considered to be neutral in terms of health, safety and comfort. There has been no formal application of this type of knowledge in the design, construction and use of buildings, as standards are set using a technical or engineering approach, where emphasis is placed on physiological responses to environments.

An interesting feature of research concerning the effects of the environment on non-physical task performance is that it is common for researchers to concentrate on the effects of a single variable in isolation. This tendency can be dated back to the first examples of such research in the 1920's, Mayo's Hawthorne Studies. These investigated the effects of lighting on the productivity of factory workers (Cole).

Contemporary noise research is frequently interested in the effects of noise created by modern IT and air conditioning installations on work performance (Bengtsson, Waye et al. 2004). Thermal research is often linked to concepts of environmental comfort, and practical studies, such as the effects of temperature on driving performance (Daanen, Vliert et al. 2003). Lighting researchers are preoccupied with the effects of lighting colour on mood and behaviour, such as the effects of shop lighting on the behaviour and mood of customers (Sharma and Stafford 2000).

Researchers examining the effects of these types of environmental variable in an educational context also follow the tradition of concentrating on a single variable. This has led to a range of studies which investigate issues such as the effects of noise or lighting on learning, concentration, and specific skills such as language acquisition (Evans and Maxwell 1997) and reading (Bronzaft and McCarthy 1975; Maxwell and Evans 2000).

The majority of environmental research in an educational context has been focussed on the learning and development of primary school children i.e. Shield and Drockrell 2003, Maxwell and Evans 2000, Lercher, Evans et al. 2003 and Hathaway 1995. This research interest has not been extended to older students, in particular university students.

Results of research on children cannot be assumed to apply to university students due to both the differences in age groups, and the different types of cognitive task which will be undertaken in their respective environments. In addition, the period of time spent in classrooms differs between primary school pupils and university students. Where pupils will generally be taught in the same room all day, for the whole school year, students move between classrooms, and may only occupy a space for an hour at a time. These differences demonstrate the requirement for specialist research examining the effects of interior environments on the cognitive performance of university students.

This small, but representative, selection of studies demonstrates the mechanistic segregation of the physical environment into individual components. This can perhaps be viewed as a consequence of the numerous journals, associations and societies that specialise in single aspects of the environment (i.e. Journal of Sound and Vibration, Institute of Acoustics, International Commission on Illumination (CIE) etc). Such research is of importance, but does not represent the complex interactions of environmental variables that take place in reality.

These examples show that in addition to the general need for research examining the effects of noise, temperature and lighting in performance in higher education environments, there is a distinct need for multidisciplinary research integrating these effects.

This research brings together these various research needs through an integrated study of the immediate effects of temperature, lighting and background noise on mood and cognitive performance in the context of university lecture rooms. These three variables have been chosen as they are the most frequently investigated environmental variables which are modified by the building envelope. They are addressed within the context of regulations and requirements designed for schools and tertiary education spaces. This research, presenting and testing their different effects through laboratory study, assesses the potential for a similar set of guidelines for use in university teaching spaces.

1.2 Aims and Objectives

The aims and objectives of the research are as follows;

I. Investigate the role of building regulations, recommendations and guidelines in defining the classroom environment in schools and universities.

II. Evaluate research investigating the effects of temperature, noise and lighting on non-physical task performance individually and as interactive variables.

III. Investigate the effects of temperature, noise and lighting on mood and performance through laboratory testing.

IV. Present aspects of the classroom which could benefit most from environmental improvement.

1.3 Thesis Outline and Unifying Concepts

Investigating the relationship between task performance and the environment is complicated, due to the immense number of possible environmental variables and types of task that can be investigated. Although environmental variables can have a range of different psychological and physiological effects, variables under investigation are often described as being potentially disturbing, acting as an environmental stressor that generates environmental stress in subjects (Bonnes and Secchiaroli). Much of the research can be unified by this central theme of environmental stress.

The idea of environmental stress allows the relationship between the physical environment and individual responses to the environment to be described in terms of strategies at a psychological level. These strategies allow individuals to cope with, adjust to, or adapt to the stressful component of the environment. This enables an overall description of effect without referring to specific psychological coping mechanisms or physiological responses to the particular environmental stimuli under investigation.

The mechanism by which environmental stress affects task performance is frequently linked to arousal (Hygge and Knez), which is both a psychological and physiological state. Arousal is a dimension of emotional reaction (as is pleasure, or dominance), a feeling state varying along a single dimension ranging from sleep to frantic excitement (Mehrabian and Russell). Certain environmental variables are thought to affect arousal levels, and subsequently affect task performance. The Yerkes Dodson hypothesis models the relationship between arousal and task performance, proposing an inverted-U shaped relationship between arousal and quality of performance (Tecce 1998). As arousal increases, performance is thought to improve, peaking at an optimal level. After this point over-arousal occurs, characterised by a state of over-excitement, resulting in performance detriment. Figure 1-1, extracted from Broadbent 1971, illustrates the relationship.

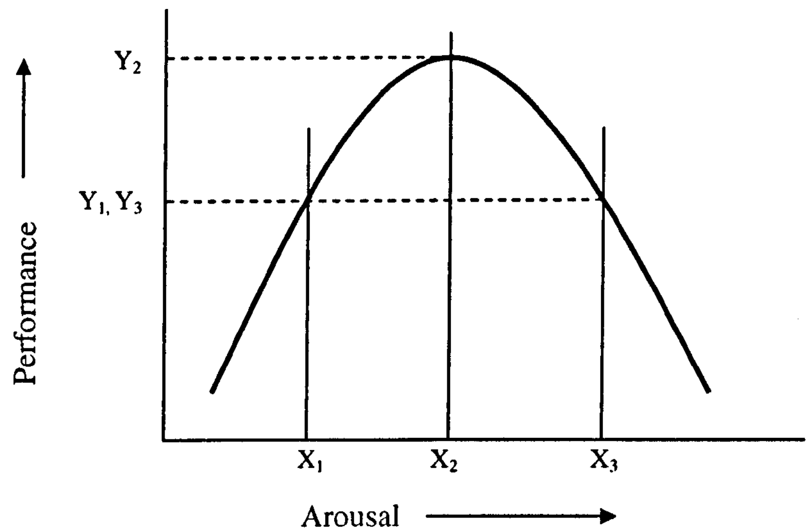


Figure 1-1 The Yerkes-Dodson Hypothesis

The inverted-U hypothesis is a theoretical rather than predictive model. A measurement of performance at a level of Y_1, Y_3, for instance, can be associated with the positive effects of arousal, at X_1 as well as negative effects at X_3. Similarly, predicting where the curve itself lies is a largely theoretical exercise. As such it cannot be used to extrapolate optimum performance levels (Y_2, X_2), or differences between tasks. It is however extremely useful for visualising the effects of environmental stress on performance.

Noise, temperature and light affect the human body in different ways, and response in terms of environmental stress and arousal may differ between variables. For ease of comparison between the variables a model of environmental stress and strain has been constructed for each variable, in Chapters 2, 3 and 4 respectively, based on the basic principles of Morris' 1995 model of factors affecting heat load in workers, shown in Figure 1-2.

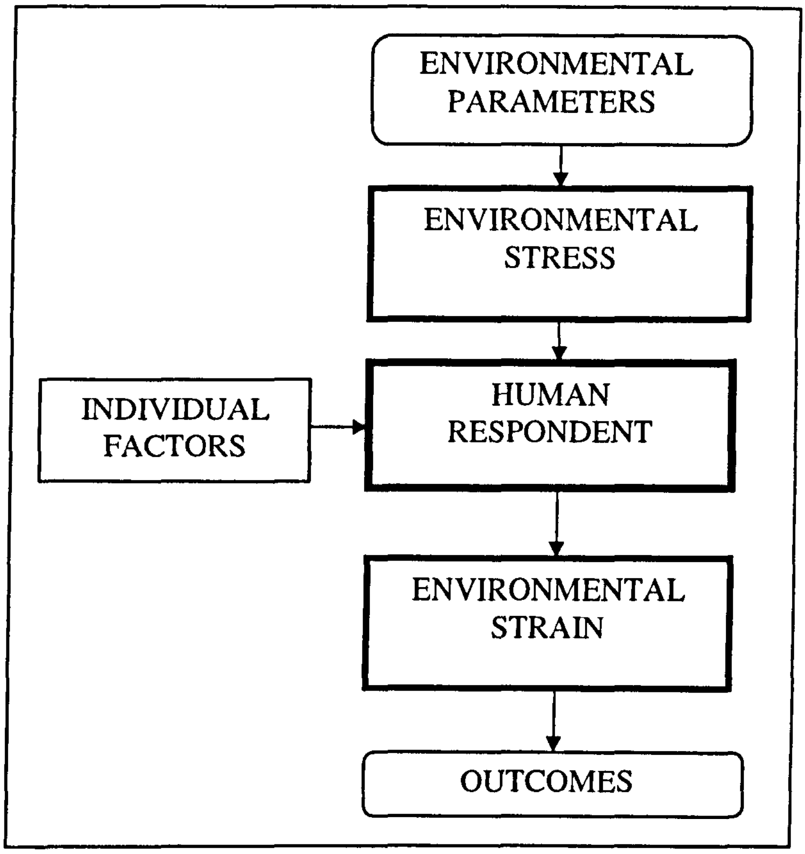


Figure 1-2 Schematic representation of stress and strain, adapted from Morris (1995)

The models clearly show the components of each variable combining to form a general level of environmental stress. This stress is modified by a range of factors which differ between individual humans, resulting in an end amount of environmental strain, which can manifest itself in a variety of ways.

Definitions of environmental strain tend to vary with the interests of the researcher. Morris (1995) for instance, interested in heat and physical performance, regards strain as a purely physiological response. Others have extended definitions of strain to include cognitive and emotional dimensions, such as MacPherson (1973), who defines environmental strain as being *"change, physiological or otherwise, induced in the individual by exposure to the environment"*. This study investigates mood and non-physical task performance, encompassing cognitive and emotional outcomes of environmental strain.

The individual effects of noise, temperature and lighting are examined in Chapters 2, 3 and 4 respectively, describing the basis for measurement of each variable. As there is little design advice available, and no legal requirement for lighting, temperature and background noise specifically in university teaching spaces, those for schools have been examined. This review of performance requirements and performance research provides the basis for Chapter 5, which discusses the interaction of these variables.

Chapter 6 introduces the methodology for the research, discussing issues such as choice of performance task and mood assessment. A preliminary study conducted to test methodology is also presented, providing the basis for the experimental design used as the basis for data collection. Results are detailed in Chapter 7, and conclusions are presented in Chapter 8.

Chapter 2: The Acoustic Environment

2.1 Introduction

In every part of domestic and working life humans are in constant receipt of sound, which has a vast array of sources and meanings. Sounds can often be signals, informing school children that class has begun, or warning the approach of emergency vehicles. They can be welcomed into our lives in the form of music, or the sound of birdsong. Sound is useful for communication purposes, particularly in the form of the human voice.

This array of sound sources and functions means that some are wanted, being necessary, and others are unwanted, constituting an environmental stressor. The term 'noise' is used to mean unwanted sound.

These examples show that noise is a very different problem to thermal and lighting provision in buildings. Where levels of lighting and temperature can be fairly well controlled in a room through its design and use, noise is largely dependant on third parties. This can be from the users of the space outside the room, such as road traffic, overhead aircraft or congregating humans. Attempts can be made to limit this type of sound transmission by careful architectural design, taking into account both location and the building fabric.

Noise from within the room is far more difficult to control, being largely dependant on the behaviour of the occupants. Other internal noise sources tend to be mechanical such as ventilation noise or IT equipment. This can often be minimised by thoughtful specification, design and installation.

Other than being useful or annoying, sound also has the potential to physically harm the human body. At suitably high intensities and exposure times noise can cause hearing disorders, from tinnitus to complete deafness. Chronic exposure to noise has been linked to effects from such as fatigue and headaches (Kjellberg, Muhr et al. 1998) to cardiovascular diseases to sleep disturbance (Raffaello and Maass 2002). Noise damage is a well explored area of research, the results of which have informed the basis of legislation such as the Control of Noise at Work Regulations (2005) .

Other areas of research concern the human response to noise in terms of non-physical effects. It has been established that noise at levels far below those required for auditory damage can induce symptoms of environmental stress such as elevated nervous system activity, or disturbances in attentional processes (Evans and Lepore 1993).

This chapter examines the physical and subjective properties of sound which are used to quantify sound. The guidelines for noise in classrooms are then examined, to show the ranges of noise that a student will be exposed to. Previous research investigating the effects of noise on non-physical task performance and mood is then examined, highlighting flaws and identifying key results.

2.2 The Acoustic Environment

Sound is defined as; "*an aural sensation caused by pressure variations in the air which are always produced by some source of vibration*" (Smith, Peters et al. 1996).

Sound propagation causes air pressures to change with no overall movement of air taking place. Sources of vibration can be as diverse as vocal chords producing speech in humans, to air conditioning units producing low frequency noises.

Noise is defined as "unwanted sound" (Everest 1994). This thesis considers noise to have two types of descriptive properties; physically quantifiable terms, such as loudness, which are fairly easily measured; and signal properties, such as type of noise, and message contained (Figure 2-1), as discussed in Cohen (1981). The following sections guide the methods used to measure noise for the laboratory study phase of the research, and begin to describe what can make noise stressful.

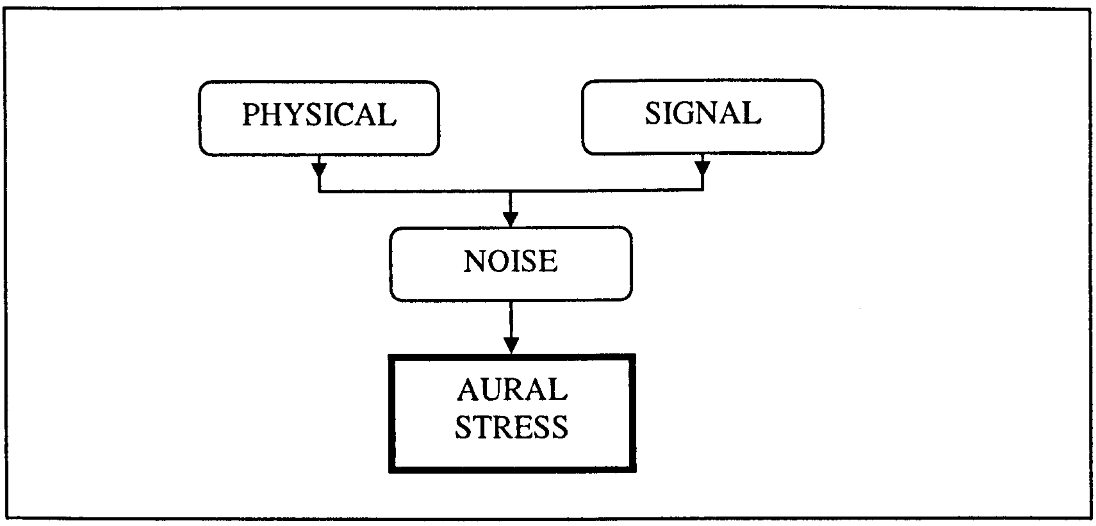


Figure 2-1 Measurement of noise

2.2.1 Physical Properties of Noise

Humans respond to a large range of sound pressures. The hearing threshold of 2 x 10^{-5} Pa is considered to be the level of the quietest sound that can be heard by a person with good ears in an extremely quiet environment At 200 Pa instantaneous damage to the ear can occur (Smith, Peters et al.).

Humans do not perceive this range of sound pressures as being linear, as the human ear is not uniformly sensitive across the spectrum. Sound pressure level (SPL) measures loudness in a way which relates to the response of the human ear. SPL relates absolute values of sound pressure (p) to a reference sound pressure value, thus;

$$SPL = 20\log\left(\frac{p}{p_0}\right) \qquad (2\text{-}1)$$

where p_0 is the reference pressure of 2 x 10^{-5} Pa, equivalent to the threshold of hearing. Using a logarithmic scale compresses the wide magnitudes of sound pressure to a more manageable range (Building Bulletin 2003).

Sound pressure level is measured in decibels, where the hearing threshold corresponds to zero dB, and the threshold of pain corresponds to about 140 dB. An increment of 3 dB reflects a doubling of the energy intensity of sound; an increase of about 10 dB is generally required for humans to perceive the change as a doubling of loudness (Cohen 1981).

In addition to pressure variation, the human ear can sense the frequency of sound Figure 2-2. The frequency of a noise is the number of vibrations, or pressure fluctuations, per second, measured in hertz (Hz) (Smith, Peters et al. 1996). Humans can detect a range of approximately 20Hz to 20kHz (Kryter).

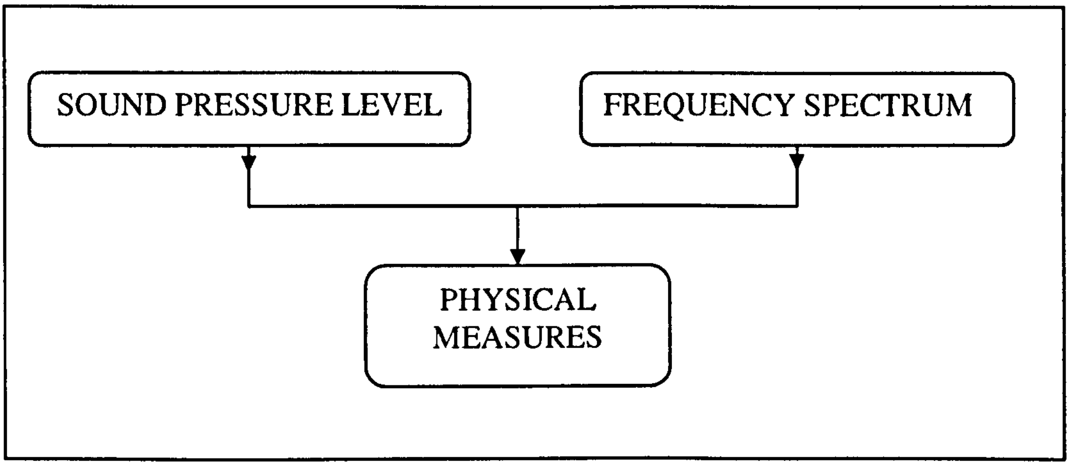


Figure 2-2 Physical Measures of Noise

Sensitivity of the human ear to frequency is not uniform across the audible frequency range. These sensitivities are by convention plotted on an equal loudness contour graph, shown below in Figure 2-3. A 100 Hz tone for example, when raised by 10 dB will be experienced as being 4 to 5 times louder, where a doubling in loudness as would be experienced at 1 kHz. Maximum sensitivity lies within the 500 to 5000 Hz frequency range, decreasing at low frequencies (Kjellberg and Landström 1994).

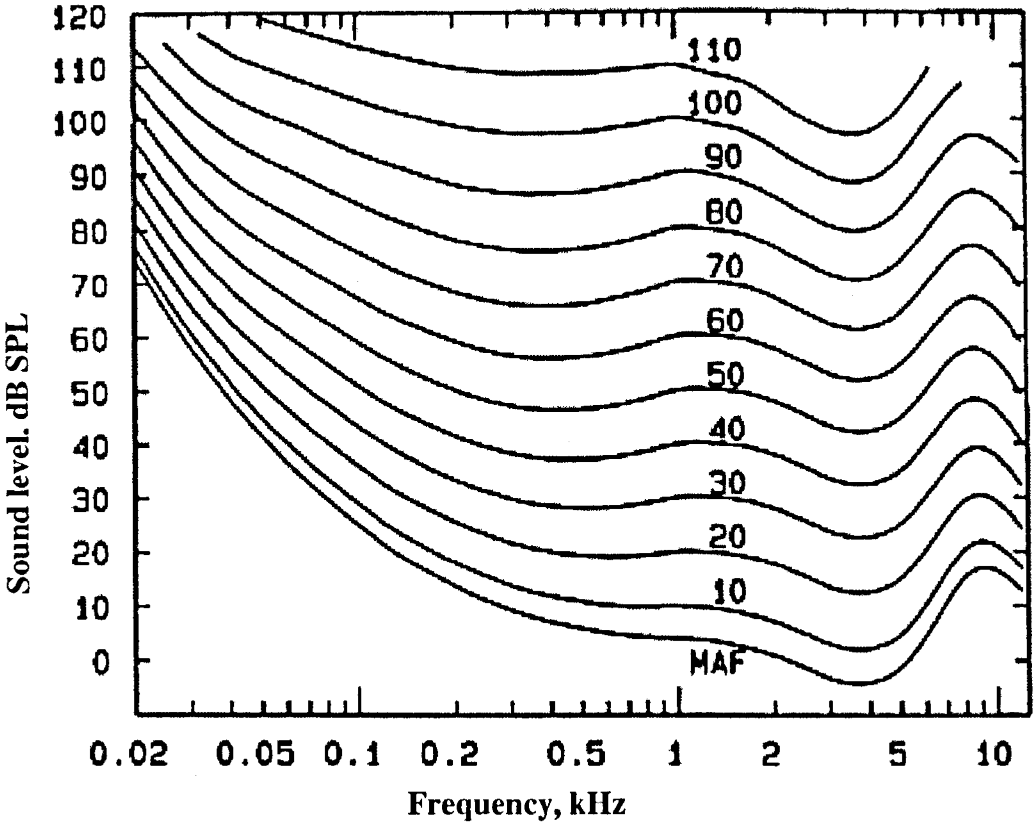


Figure 2-3 Equal loudness contours of the human ear

To reflect these variances in the sensitivity of the human ear to both frequency and sound pressure, different scales are used to weight frequencies dependant on the characteristics of noise being measured.

The A weighted decibel scale (dBA) is based on an equal loudness curve at a very low level (40 dB), where the difference between sensitivities to different frequencies is large. It is the most frequent measure of noise used in behavioural studies (Cohen 1981). Being virtually unaffected by the low frequency components of a noise, it is inappropriate for use in studies examining the effects of strong low frequency noise components, such as ventilation noise (Kjellberg and Landström 1994).

Noises composed of a single frequency are known as pure tones. In everyday life background noise will normally be far more complex, consisting of multiple tones that can vary in amplitude over time, i.e. fluctuations in traffic noise. These types of noise can be described in terms of sound level is exceeded over a measured period of time (T);

$L_{A10,T}$ = sound levels in dB(A) which is exceeded for 10% of T
$L_{A50,T}$ = sound levels in dB(A) which is exceeded for 50% of T
$L_{A90,T}$ = sound levels in dB(A) which is exceeded for 90% of T

As such, L_{90}, is more of an overall indicator of the background noise level, where L_{10} indicates peaks of noise.

L_{eq} is the sound pressure level of a steady sound, which, over a given period, has the same energy as the fluctuating sound in question. It is an average, and is measured in dB. Performance research generally employs A-weighting, therefore the A-weighted sound pressure level L_{Aeq} should be used .

Measurement of noise for the purposes of performance research is generally restricted to recording the sound pressure level. Whilst this gives an indication of the perceived loudness of a noise, it gives no indication of the spectral content of the noise; i.e. the proportion and combination of the different frequencies present.

Spectral content can easily be presented graphically, but is underused by researchers interested in performance, who tend to instead use more descriptive characteristics of noise, discussed as follows

2.2.2 Descriptive Properties of Noise

The loudness or spectral content of a noise does not necessarily correlate with the amount of distraction or irritation generated. It has been shown, for example, that phones left ringing at vacant desks in offices are more annoying than the sound of a phone ringing in general, with co-workers becoming irritated at the absentee

(Banbury and Berry). This type of noise problem requires a more subjective description of its qualities than can be provided using quantifiable measurements alone. Four main descriptive properties of noise have been identified, illustrated in Figure 2-4 and described as follows.

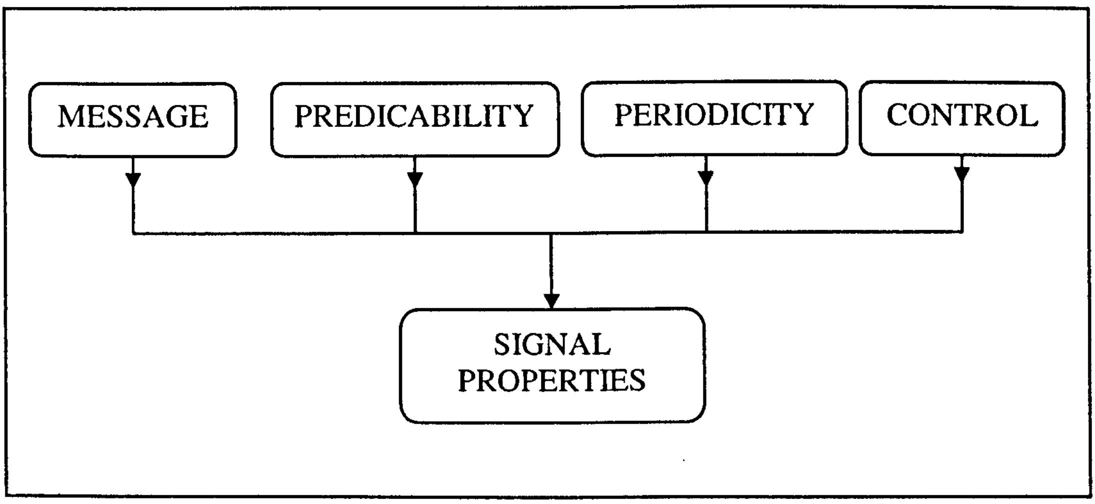


Figure 2-4 Signal Measures of Noise

Noise in classrooms will often involve an element of background human speech. This can come from a variety of sources such as other students in the room, a lecture in an adjacent classroom or students gathering outside in the corridor. Boman and Enmarker (2004) conducted a survey of pupils' responses to disturbing noise sources in school. Chatter in classroom, sounds from the corridor and scraping noises from furniture were found to be the most disturbing sources, and pupils found noise to be most disruptive in mathematics, native language classes, and foreign language classes.

Speech as background noise has particularly interesting effects, especially on tasks with a communication element. Broadbent (1952) wrote extensively on this subject, examining problems such as the difficulty of speaking and listening simultaneously, and of listening to relevant and irrelevant messages simultaneously. It has been suggested that a background noise of speech may interfere with hearing one's own internal speech (Cohen 1981). The intelligibility of the speech appears to correspond with how disturbing it is (Kjellberg, Landström et al. 1996).

Kjellberg, Landström et al. researched signal characteristics of noise, in order to find which aspects of noise were the source of annoyance and distraction in office workers. He found that predictability and controllability of a noise were them most important factors. Those who believed that that possibilities to lower sound level were great, were more annoyed and distracted by the noise than those who thought that the possibility did not exist. Glass (1971), in Gawron (1984), had previously arrived at similar results, finding that subjects that believed they had no control over a noise were significantly more tense than subject who believed they could control the noise.

The periodicity and predictability of a noise are also used to describe the characteristics of an intermittent noise. Intermittent noises can be predictable, or unpredictable. It is thought that individuals can mentally prepare themselves if a noise is predictable, resting during periods of no stress, and so constant noise appears to be easier to habituate to than variable noise, and is consequently generally regarded as being less annoying. Similarly, an expected noise is less annoying than an unexpected one (Kjellberg and Landström 1994; Kjellberg, Landström et al.).

2.2.3 Individual Factors

The same noise will prompt a variety of different reactions between different people. However, these differences are not clearly attributable to demographic variables such as sex and age. The only group that shows a generally shared response to noise are those with a hearing impairment. This could be attributed to lower noise levels becoming annoying due to interference with speech intelligibility (Kjellberg and Landström).

Personality type has been shown to affect mental performance in noise. Belojevic, Slepcevic et al. (2001) found that extroverted subjects performed a mental arithmetic task significantly faster when subjected to noisy recorded street noises (88 dBA) when compared to the same noise at a quieter level (42 dBA). Findings by Furnham and Strbac (2002) support the notion of introverts being more negatively affected than extraverts by background noise. Three varieties of background noise; silence, music, and office noise, were used, although no measure of level was made. Reading comprehension by introverts was lower than that of the extroverts in the presence of noise and music, but not silence. This may be linked to the findings of Kjellberg and Landström et al., where self reported sensitivity to noise was reported to correlate with both annoyance and distraction.

2.3 Recommendations for background noise

Students in a classroom are subject to a range of background noise, from sources within the room, such as other students, or sources out with the classroom. Noise can be transmitted through the walls, floors and ceilings of a room, as well as through open windows and ventilation ducts. Sound transmission between spaces is an important area of acoustic research in the built environment, forming the basis for many building regulations and standards, such as Part E of the Building Regulations, applicable to most buildings (ODPM 2000).

The School Premises (General Requirements and Standards) (Scotland) Regulations 1967, and the 1973 and 1979 amendments to those regulations , make no specific requirements for background noise levels, other than requiring school buildings to be insulated against disturbance as "appropriate", with the English school premises legislation making a similarly inexact requirement .

The Scottish Executive publication, 'School design: Optimising the internal environment' advises that Building Bulletin 93 be used as a starting point for design guidance in schools. Building Bulletin 93 details construction standards for acoustics in new school buildings, recognising the importance of acoustics on teaching and learning activities. The performance standards for indoor ambient noise levels, as detailed in Building Bulletin 93, are shown in Table 2-1.

Indoor ambient noise levels are regarded by Building Bulletin 93 as being inclusive of external noise sources, such as traffic, industrial or commercial noises, and building services noise. It excludes teaching activities in the room, any specialist teaching equipment present, and rain noise. The upper indoor ambient noise limits are low, comparable to a quiet home.

Table 2-1 Indoor ambient noise levels from Building Bulletin 93

Type of room		**Upper limit for the indoor ambient noise level L_{Aeq}, 30 min (dB)**
Primary school: classrooms, class bases, general teaching areas, small group rooms		35
Secondary school: classrooms, general teaching areas, seminar rooms, tutorial rooms, language laboratories		35
Open plan:	*Teaching areas*	40
	Resource areas	40
Lecture rooms:	*Small (fewer than 50 people)*	35
	Large (more than 50 people)	30
Study rooms (individual study, withdrawal, remedial work, teacher preparation)		35
Libraries:	*Quiet study areas*	35
	Resource areas	40
Indoor sports halls		40

It should be noted that the indoor ambient noise is defined in term of the A-weighted decibel scale. As described in section 2.2.1, it is virtually unaffected by the low frequency components of a noise. For this reason it is not a suitable measure of ventilation noise, which is considered to be part of the indoor ambient noise measurement, especially taking into account the findings of researchers such as Waye and Ryelander et al. (1997), Bengtsson (2004); Bengtsson, Waye et al. (2004) and Benton and Leventhall (1986), all of whom measured non-physical effects of low frequency noise. As such, students could be benefited by the introduction of an additional upper noise limit expressed in terms of the C-weighted decibel scale, a more appropriate measure for this type of noise.

2.4 Background Noise and Performance

Where the physiological effects of noise have been well researched, the non-physical effects are less well understood. This section presents a range of studies considering three general types of non-physical effect; mood, performance and comfort (Figure 2-5). The relationships between comfort, mood and performance are complex, each being intrinsically interlinked and interdependent. An individual's mood can affect the way they react to their surroundings, consequently influencing their perceived level of comfort. The opposite is also true, as the level of comfort experienced by a person can also affect mood. Mood and comfort can both affect performance level, and an individual's opinion of their own performance can affect mood. Such complex interactions mean that there is no simple chain of cause and effect between the three variables. In order to be able to further examine the relationships between them, they are measured as being three separate variables throughout this thesis.

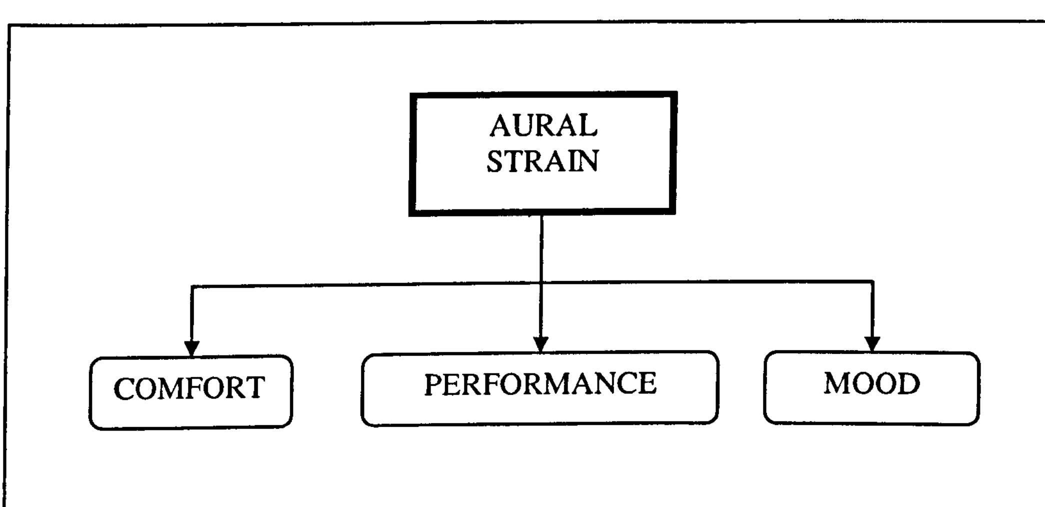


Figure 2-5 Non-Physical effects of noise

Of all environmental stressors, noise is the most extensively researched (Raffaello and Maass 2002), and the effects of noise have been examined in many industries. Prior to World War II research mainly concentrated on industrial output being affected by the noisy conditions of factories of the time (Broadbent 1971). Low frequency noise generated by modern technologies such as ventilation and heating systems, and computer network installations, provide a focus for modern noise researchers. These studies tend to be laboratory based, and have studied attention, motivation and tiredness (Bengtsson, Waye et al.), as well as annoyance (Bengtsson), performance and work quality (Waye, Ryelander et al.).

Interest has also grown in the various effects of noise on the learning of schoolchildren. Studies as diverse as the affects of aircraft noise on reading and language acquisition (Evans and Maxwell), and train noise (Bronzaft and McCarthy) and sound attenuation work in classrooms (Maxwell and Evans) on reading ability, have been undertaken in the field. Studies of noise in office environments, where investigations of employee concentration (Banbury and Berry), annoyance and distraction (Kjellberg, Landström et al.) have also taken place in the workplace.

As outlined in section 1.3, environmental stress can be associated with measurable changes in the human body. Altered levels of cortisol, for instance, are associated with stress, sometimes associated with classrooms with poor or no natural day lighting (Küller and Lindsten 1992). Likewise, noise has been associated with physical symptoms of environmental stress. Melamed and Bruhis (1996) conducted a study in the field of industrial workers chronically exposed to noise exceeding 85 dBA. Altered patterns of urinary cortisol, accompanied by symptoms of fatigue and irritability were measured.

Environmental stress generated by noisy conditions can affect productivity. Raffaello and Maass (2002) found that quieter working conditions encouraged greater satisfaction in workers, with increases in environmental and job satisfaction, reporting less stress headaches and sleep disturbance, and easier communication with colleagues. The study tracked the effects of workers who had moved to new, quieter office. As such, some findings, such as increased attachment to their employers and a more positive image of the company, could be attributed to motivational aspects of the employer's investment in higher quality premises, in addition to the noise reduction factor suggested by Raffaello.

As with studies of lighting and temperature on performance, predicting the effects of noise is made problematic by the range of different performance tasks which have been employed over the years in research. In addition to this, it is common for researchers to test performance in the presence or absence of various types of background noise i.e. Gawron (1984), rather than assessing the effects of the same noise at a range of sound pressure levels on performance.

A range of experiments measuring the effects of noise on performance were published in the 1970's and 80's, following on from earlier research of noise and vigilance, which stems from men keeping watch for inconspicuous signals during fairly long periods (Broadbent), e.g. monitoring radar screens. The types of task used in vigilance studies are often scored in terms of signals correctly identified, signals missed, and signals erroneously identified. This allowed Broadbent, in 1978, to be quite specific about the effects of noise;

"high false alarm rates... increase in the number of instants of inefficiency, resulting in errors or occasional slow responses... concentration on some parts of a complex display at the expense of others."

An earlier study by Weinstein (1974) partially confirms Broadbent's assertion. The effects of background noise and silence on proofreading, using an intermittent teletype noise on 33 American college students were examined. Students worked more slowly and less steadily during noise bursts, but more accurately. Weinstein theorises that subjects may be "taking greater care during noise than during quiet". This supports various aspects of Broadbent's idea that noise creates an inconsistent work pattern of work, but does not indicate that overall performance is detrimentally affected.

Conrad (1973) used a serial decoding task, conducted in 93 dBA of white noise, and 38 dBA of ambient silence. The task required problem solving skills, and little or no detrimental effect was found. It is possible that this task was not sufficiently difficult, noisy, or distracting, to cause mistakes. In addition to this, task performance was measured purely by errors, so any effects of noise on speed of performance will have remained unmeasured.

Smith and Broadbent (1980) used an embedded figures task, where subjects have to find a target shape in a complex visual pattern. No effects of noise on performance were found in either the 85 dBC or 55 dBC conditions. Smith attributes this to the type of task employed, but the lack of measurable effect can be more fully explained by the scoring system used. Points were awarded for each figure found, and a maximum of 16 points were available. Subjects generally managed to complete around eight and nine figures in a session. These very low scores make the embedded figures test highly insensitive, meaning that although noise may have had an effect on task performance, a far longer exposure time or number of figures would be needed to measure it.

Gawron (1984) administered tests of mathematical, reading and vocabulary to subjects exposed to traffic noise levels of 85 and/or 45 dBA, and found no statistically reliable effects on performance, despite subjects rating both their mood and the environment more negatively in the noisier condition. As with Conrad's study, performance was measured in terms of correct answers to the task, and did not measure any effects that the conditions may have had on speed.

More recently, Furnham and Strbac (2002) investigated the effects of background noise type on reading comprehension, a reading memory task and mental arithmetic. Conditions with no background noise produced better overall performance on tasks of reading comprehension and memory, when compared to conditions with music or office noise. Mental arithmetic performance was however unaffected by the type of background noise. Similarly to Conrad and Gawrons's studies, the types of task set by Furnham were measured in terms of correct answers, and there was no measure of how speed of work was affected by performance. As such the speed of mental arithmetic could have been affected by the noise types, but been unmeasured.

Hygge and Boman et al. in 2003 conducted a study examining the effects of road noise and meaningful irrelevant speech on different memory systems. It was found that both meaningful speech and road traffic noise were detrimental to memory recall of text. The semantic content of the speech did not interfere with processing of semantic information any more than the non-semantic road traffic noise. Hygge draws comparisons with a number of studies that have found that non-speech auditory signals exhibiting appreciable acoustic variation or change between its components causes a deficit in memory performance, suggesting that the traffic noise used may have had such a high variability as to impair performance as much as the semantic content of speech

Whilst the effects of noise on performance have been the subject of continuing research over many years, the relationship between mood and noise remains relatively unexamined. Gawron reviewed the small selection of work available in 1984, and reports several instances where increased decibel level has a direct relationship with annoyance and discomfort. His own research failed to find any direct link between noise level and performance, but did find that subjects rated their mood more negatively in noise.

This selection of studies has examined some of the methodological issues surrounding this type of research, in addition to discussing the non-physical effects of noise on performance. The principle of Building Bulletin of encouraging reduced noise in classrooms appears to be a valid one, with experimental research demonstrating instances of increased performance in such conditions.

2.5 Discussion

The acoustic environment is becoming increasingly important in the design of schools, as is evidenced by the range of research and building available. This research interest has not yet been extended to environments provided in further education institutions.

This chapter has examined a range of issues relevant to investigating the effects of noise in educational environments, allowing the assembly of the model shown in Figure 2-6. This model shows physical and subjective characteristics of noise combining to create environmental strain.

It is interesting to note the difference in approach to describing the qualities of noise between researchers and those composing the environmental guidelines in schools. Generally, researchers address noise in descriptive terms, discussing the differences between different types of noise. The Building Bulletins, on the contrary, are less interested in signal content, and only detail physical measures of the environment. The results of performance research, however, indicate that noise type can affects performance as much as sound pressure level. As such, there may be scope for the Building Bulletins to expand their scope, and address noise type. Boman and Enmarker's 2004 study, for instance, identified the noise from chairs being scraped on the floor as being particularly distracting and annoying to students. This noise complaint has the potential to be controlled by the Building Bulletins, i.e. by setting specific requirements for floor coverings.

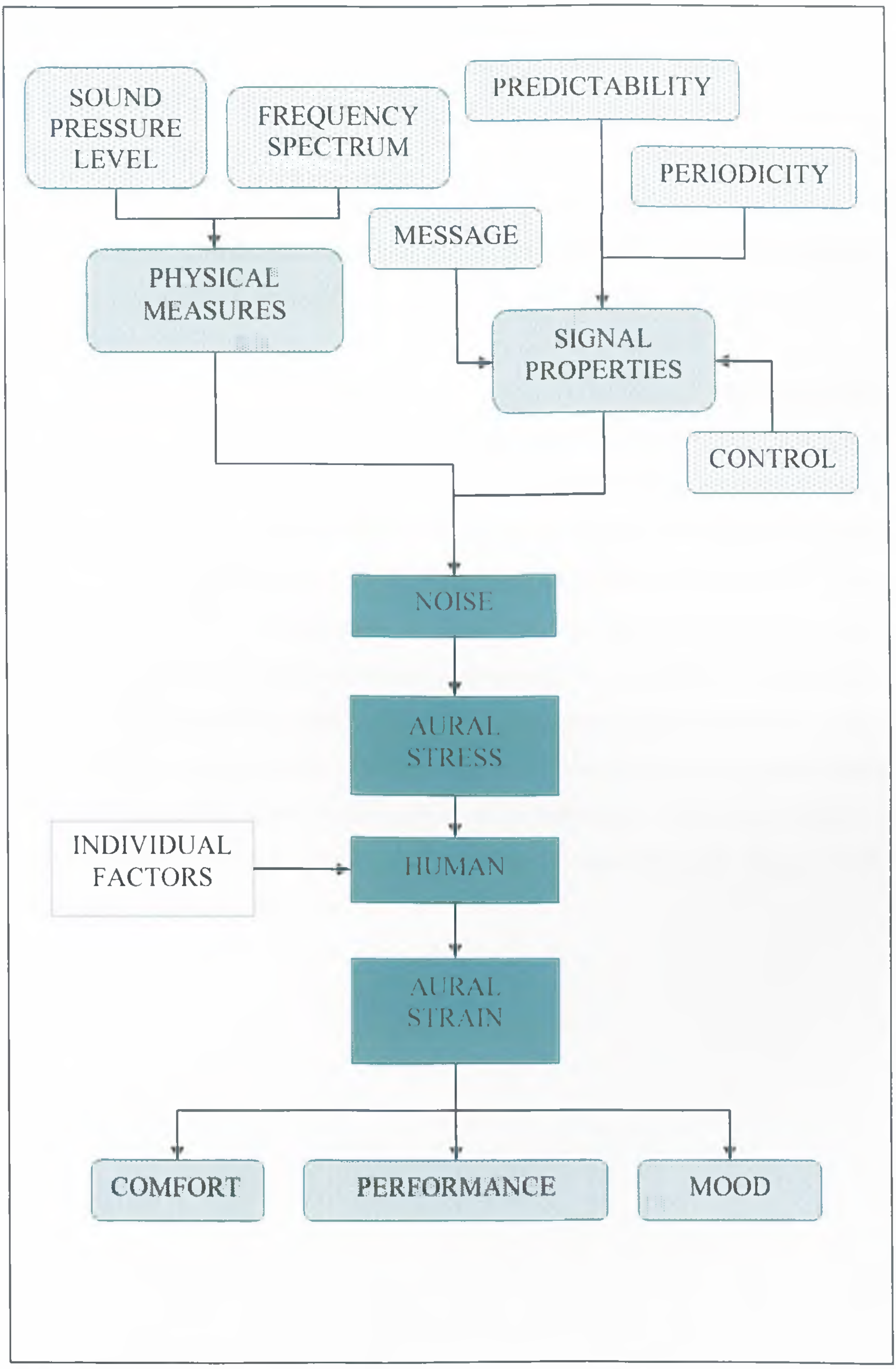


Figure 2-6 Noise stress and strain, based on Morris (1995)

This lack of similarity between academic research and the Building Bulletins' treatment of noise causes further difficulties. There has been little research measuring the effects of the same background noise at different sound pressure level. As such, there are no formalised results of research for the standards that have been set by the Building Bulletin for background noise levels. The methodology of this research addresses this part of the problem, whilst recognising that noise type is also important to non-physical performance.

Broadbent's assertion in 1978 that noise has the potential to slow performance and increase the rate of errors can still be broadly supported, as can other researchers' more general findings of increased noise being detrimental to performance. However, several studies have failed to find any correlation between performance and noise. It is suggested that this is due to the use of tests where only a single measure of absolute performance is generated i.e. the number of correctly remembered answers, or number of codes decoded. As a decrease in the speed of performance has been shown to be affected by background noise, these researchers have failed to measure an effect which may have been present, by concentrating only on errors, rather than overall quality of performance. This is an important result for all research of this nature, highlighting the importance of an appropriate choice type of performance test.

Chapter 3: The Thermal Environment

3.1 Introduction

The thermal environment is the most complex of the three variables under investigation, being composed of a complex interaction between environmental variables. The relationship between the humans and the thermal environment can be highly individual, with no thermal environment completely satisfying everyone (Karjalainen 2007). Standards are therefore set at levels which are predicted to please most people – i.e. ISO 7730, which is intended to result in 80% occupants finding the conditions acceptable (Toftum 2002).

This chapter begins by describing the factors that create a thermal climate in a classroom, and their various effects on human physiology. The overall thermal environment can be measured in a variety of ways, and the appropriateness of the various methods for use in performance research is discussed. As there are no specialist standards for university classrooms, guidelines for thermal conditions in schools are considered. These sections provide the basis for a review of research which has examined the effects of the thermal environment on non-physical task performance.

3.2 Humans and the Thermal Environment

Humans frequently describe thermal environments in terms of hot and cold. These sensations of thermal stress are based on information received by temperature receptors in the skin. These receptors do not sense absolute temperatures, but are instead stimulated by changes in temperature. Receptors adapt quickly to particular levels of stimulation, and if there is no change in temperature, the nerve endings stop discharging. The hypothalamus, located in the brain, uses information from the sensors in conjunction with blood temperature to relay output to various centres in the body, modifying heat loss and to a lesser extent heat production (Clark and Edholm) using control mechanisms such as goose-pimples, shivering, perspiration and altered rates of metabolic activity and respiration (Smith and Bradley 1994).

Thermal stress affects the human body in a variety of ways. Prolonged exposure to extremely hot or cold conditions can cause hypothermia or hyperthermia (Haslam and Parsons) and ultimately prove fatal. Localised effects of thermal strain can also occur, such as a loss of dexterity due to cold hands (Enander), at skin temperatures of around 30 to 31°C (Holmér 1994b). Capacity for prolonged energetic work is reduced when core body temperature drops below 36°C (Holmér). Such factors are important to physical task performance.

Due to the requirements of the Workplace Health and Safety Regulations (1992) university students should not encounter thermal conditions in classrooms which endanger health, even though there may not be a consensus that the climate is comfortable.

Three main determinants of thermal stress have been identified; the thermal climate itself; the clothing of the occupants; and the type of activity being performed in the space (Figure 3-1). These are discussed as follows.

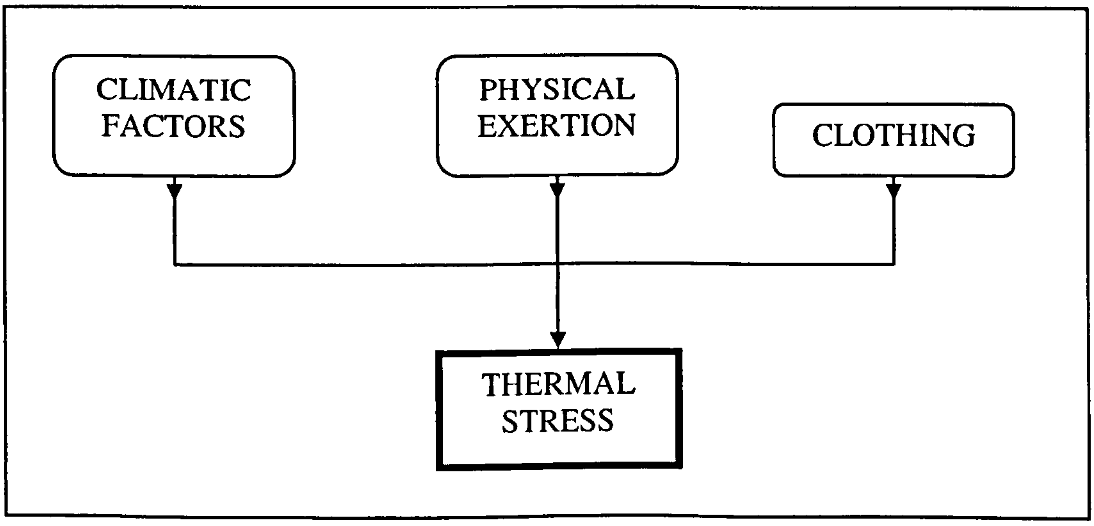


Figure 3-1 Contributors to Thermal Stress

3.2.1 Climatic Factors

The thermal environment is considered to be composed of four climatic variables; air temperature, humidity, radiant temperature and air velocity, (MacPherson; Morris; Müller and Hettinger 1995; Oleson; Parsons 1995; La Gennusa) as shown in Figure 3-2. BS EN ISO 7726:2001 provides definitions and standards for their measurement in rooms.

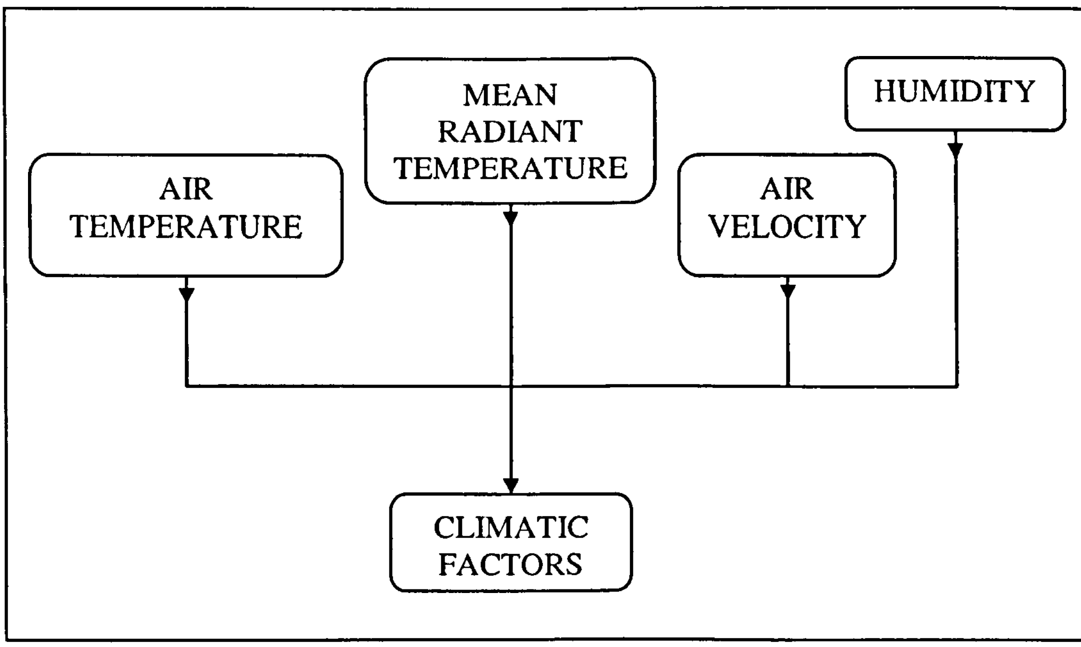


Figure 3-2 Climatic Factors

Air temperature within rooms is generally measured in degrees Centigrade (°C), and is usually measured by a thermometer. It is an important determinant of thermal loss or gain, affecting the exchange of heat between skin and adjacent air. When skin temperature is higher than the air temperature, the air next to the skin becomes heated and buoyant, rising to form a natural convection boundary layer flow (Clark and Edholm).

Every surface of a room will emit radiation, as will the people and objects within. The amount is dependant on surface temperature and surface emissivity. This is an important method of human body heat loss. All objects also absorb radiation

(Speakman). If the radiation from a surface or object meets another body it will produce a disturbance to surface molecules and raise their temperature. A common example of this is the sensation of heat created by direct sunlight on the skin.

The mean radiant temperature of a room is measured in degrees Centigrade (^oC), and integrates the generally heterogeneous radiation from the walls into a mean value. Measurement methods, usually using black globe thermometers, can be used, as well as calculation methods which use measured values of the temperature of the wall, the size of the wall, and their position relative to the occupant. It is considered the most complex parameter to measure, as an accurate measure should include not only thermal radiation from low temperature surfaces such as walls, but also high intensity sources such as solar radiation (La Gennusa).

Air velocity is the speed of the air, generally measured in metres per second using an anemometer. Air flows are often described by mean velocity, which averages flow over an interval of time. Humans begin to feel air movement at approximately 0.2 m/s. Air speed in most naturally ventilated rooms is generally less than 0.1 m/s (1999).

In the absence of air movement, the body is surrounded by the natural convective flow. Introducing airflow over the surface of the skin increases the rate of convection by elevating surface heat losses (Speakman). Consequently both body movement and air movement can have a cooling effect. Wigö (2005), found no effects of air velocity variations on cognitive performance, but confirmed that perceived pleasantness of indoor climate could be met at higher temperatures when air velocity variations are present, than otherwise (Wigö and Knez 2005)

Absolute humidity of the air is a measure of the amount of water vapour in the air, whereas relative humidity gives the amount of vapour in the air in relation to the maximum amount it could contain at a given temperature and pressure. This is often expressed as a percentage (RH %). Humidity levels determine how well humans can lose heat through evaporation.

Unlike conduction, convection and radiation, where heat flows down the temperature gradient, evaporation allows heat to be lost, even when the object is cooler than the surrounding medium (Speakman). Evaporation occurs with exposed liquid, where vapour diffuses from the surface with the extraction of latent heat from the remaining liquid. As the body can regulate sweat output within wide limits, this method of heat exchange can be the dominating factor in maintaining overall heat balance particularly under exercise or in hot environmental conditions. Evaporation from the skin's surface can take place even though there is no active sweating and the skin is still wet. This, together with evaporation of water during expiration is known as insensible evaporation (Clark and Edholm).

At high humidities net evaporation from the surface decreases as the air becomes saturated (Speakman). Humans find humid conditions more uncomfortable than hotter drier conditions, as the ability to lose heat through evaporation becomes more difficult.

These four climatic factors interact with each other to create different effects on the human body. For instance, if air temperature is below skin temperature, an increase in air velocity will exert a cooling effect, but if air temperature is above skin temperature the same increase can instead have a heating effect (MacPherson).

Studies investigating the effects of the thermal environment on performance often measure only air temperature. Whilst it can be reasonable to assume that conditions in a climatically controlled test chamber have no appreciable levels of radiative heat or air movement (Ramsey and Kwon), failing to measure humidity is remiss, especially at high temperatures. Vasmatzidis, Schlegel et al. found high relative humidity (70%) detrimental to performance at 34°C. This is concordant with the accepted view that the effects of humidity on thermal comfort are limited up to temperatures of around 26°C . Whilst air temperature is generally measured, humidity levels often remain unrecorded in literature concerned with effects of thermal climate on task performance.

3.2.2 Clothing

Clothing has three main properties which affect the transfer of heat between the body and the environment; thermal resistance (insulation), vapour resistance, and ventilation (Figure 3-3). These affect heat loss by evaporation, convective heat loss, radiative heat loss, and heat loss by conduction (Butera).

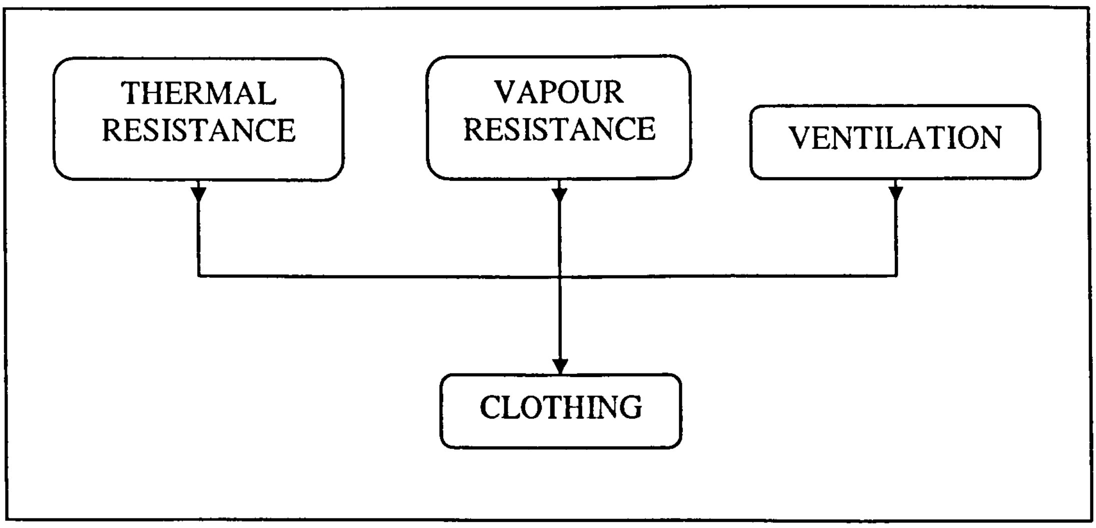


Figure 3-3 Properties of clothing affecting heat stress

Convection to and from the body is affected by the thermal resistance of clothing (Bernard, Dukes-Dobos et al.). As insulation increases, heat exchange reduces. This can prevent loss of body heat, keeping the wearer warm, but can also result in overheating.

Permeability is the ability of water vapour to pass through clothing (Bernard, Dukes-Dobos et al.). Permeable clothing allows sweat to evaporate to support cooling. As human skin is always moist (Oseland), vapour permeability can have important effects on thermal comfort and thermal balance.

Heavier clothing is associated with interference with a person's heat dissipation abilities, due to these changes in insulative and permeability characteristics (Ramsey and Kwon 1992).

Ventilation characteristics refer to the movement of air through openings in clothes, and the material (Bernard, Dukes-Dobos et al.). High ventilation usually enhances cooling through evaporation.

It should be noted that that these values apply to the garment being worn on their own. In most circumstances a down jacket would be worn with additional layers underneath, so that the total operative temperature would be higher than the 3.4 °C change quoted.

It should be noted that that these values apply to the garment being worn on their own. In most circumstances a down jacket would be worn with additional layers underneath, so that the total operative temperature would be higher than the 3.4 °C change quoted.

Table 3-1, extracted from BS EN ISO 7730:2005 Ergonomics of the thermal environment, shows the partial clothing insulation values (I_{clu}) of various garments, with the corresponding change in temperature necessary to remain neutral when a garment is added or removed at a light sedentary activity.

It should be noted that that these values apply to the garment being worn on their own. In most circumstances a down jacket would be worn with additional layers underneath, so that the total operative temperature would be higher than the 3.4 °C change quoted.

Table 3-1 The partial clothing insulation values (Iclu) of garments

Garment	**I_{clu}**	**Change of optimum operative temperature (°C)**
Thin Sweater	0.2	1.3
Thick sweater	0.35	2.2
Light summer jacket	0.25	1.6
Down jacket	0.55	3.4

This table demonstrates the importance of clothing as a variable when assessing temperature effects, which should be treated as a variable to be controlled. Most studies require subjects to wear normal indoor clothing for testing, with the notable exceptions of studies which require core body temperature to be manipulated. Allnutt and Allan (1973), for instance, dressed participants in a liquid suit, and Provins, Glencross et al.)1973) immersed subjects in a bath of water.

This tradition of using normal clothing is useful for this study as students will generally wear typical indoor clothing during lectures, removing outer jackets soon after entering the room.

3.2.3 Physical Exertion

Metabolic heat generated by a person increases as a function of physical workload (Ramsey, Bernard et al.). Thermal comfort can be maintained by cooling the thermal climate in such situations. Pupils and students typically remain seated at a desk for the duration of a lecture, tutorial or examination, and the only physical exertion required will be from small tasks like note taking. As such the effects of physical exertion are negligible for the type of tasks relevant to this study.

3.2.4 Individual Factors

Thermal comfort is a state of mind which expresses satisfaction with the thermal environment. No thermal environment will completely satisfy all the occupants of a room, due to individual responses and preferences. These individual factors tend not to be demographic, other than gender, for which small differences in thermal response have been found. These are usually attributed to differences in clothing, but some instances where clothing has been controlled have found small effects.

Karjalainen (2007), for instance, found that in domestic settings females preferred higher temperatures than males, but used their thermostats less often. This could be attributed to gender differences in attitudes to HVAC systems and confidence in use of thermostats, rather than differences in physiology. Shoemaker and Refinetti (1996), found an effect of the daily circadian temperature cycle on the thermal preferences of men, where high ambient temperatures were preferred when their body temperature is high, and low temperatures preferred when body temperature is low. This difference in preference was small. No such effect was found on females.

Factors such as heat tolerance and acclimatisation to thermal conditions are more significant in modifying individual responses to the thermal environment (Figure 3-4). Heat tolerance is the ability of a person to physiologically adjust to a heat stress exposure. Tolerance is largely related to factors such as fitness and acclimatisation state. Acclimatisation is an important physiological mechanism to enhance heat intolerance (Bernard, Dukes-Dobos et al. 1994).

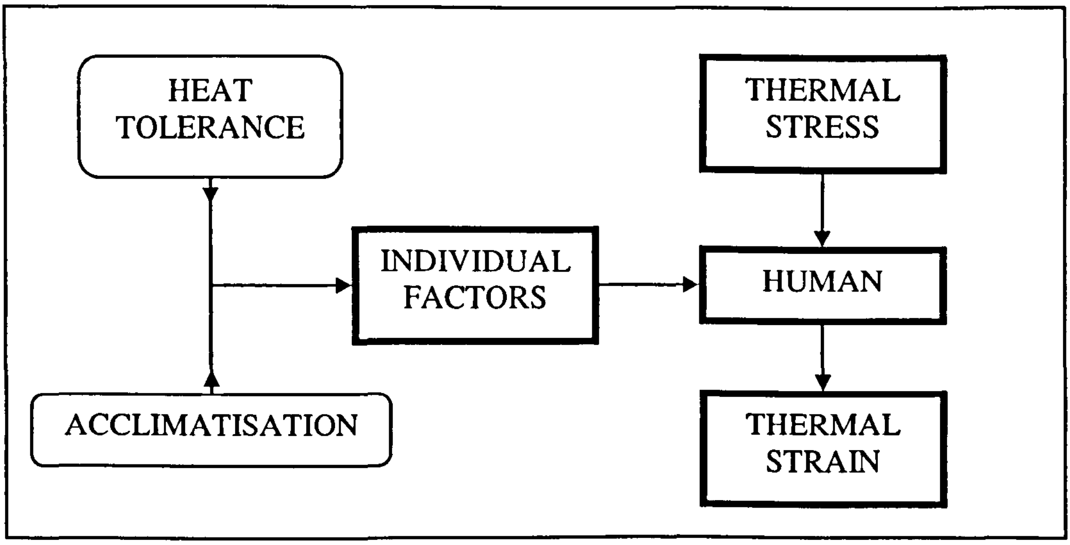


Figure 3-4 Individual factors modify responses to heat strain

About five successive days of one or two hours of exposure to the temperature and the task are required for successful acclimatisation (Bernard, Dukes-Dobos et al. 1994). Acclimatisation to heat is characterised by an increase in sweat production, removing more heat through evaporation. Heart rate and body temperature tend to also respond more effectively, and the risk of heat strain is reduced (Ramsey, Bernard et al. 1994). The length of time required for acclimatisation means that school pupils will be more likely to acclimatise to their working environment than university students.

Physical fitness has a variety of implications for task performance. A fit person will be able to perform a physical task with a lower core temperature than a less fit person. If the temperature becomes such that heat cannot by dissipated by an individual, cardiac demands will be greater on the less fit person (Bernard, Dukes-Dobos et al. 1994). The impact of physical fitness is assumed to be negligible for the non-physical tasks in this study, but it should be noted that the effects of physical fitness on non-physical task performance under environmental stress remains unexamined.

3.3 Measurement and assessment of thermal environments

Measurement of the thermal environment can be extended beyond simple measurements of radiative heat, air movement and temperature and humidity. Many attempts have been made to create indices integrating these variables, to produce an overall measure of the thermal environment.

One such index is Effective Temperature (ET), combining temperature and humidity measurements, appearing in its earliest form in 1923 (Bell and Provins). Two environments with the same ET should evoke the same thermal response from an individual, even although the levels of air temperature and humidity may be different, provided air velocity is constant (ASHRAE).

The effectiveness of ET is disputed by several authors. Bell and Provins (1962) criticises the small sample size used to construct the index, arguing that as the original experiments used only three participants, even taking into account subsequent revisions of ET, that there is no valid basis for the scale. The accuracy of the ET has been disputed, with corroborative studies showing that ET overestimates the heating effect of humidity (Givoni and Rim). More recently the idea of any form of universal heat stress index at all has been considered "unworkable" by some (Morris 1995), or impossible to design perfectly by others (Parsons 1995). Despite such criticisms, there are many ongoing efforts to create similar indices. The inherent inaccuracies of such indices render them unsuitable for use as a measurement of the thermal environment in performance studies.

The Wet Bulb Globe Temperature (WBGT) scale has often been used to describe the thermal environment in performance studies. Unlike ET it is an entirely objective measure of the environment, integrating the effects of humidity, air movement and air temperature when applied indoors (1972).

Although indices such as the WBGT do not include a subjective element, they can still be incomplete descriptions of the environment. As with ET, various different combinations of climatic factors can result in the same measure of temperature. The precise combination of climatic factors may be important, as different combinations may have different effects.

The variety of indices and scales used to measure the thermal environment also complicate comparisons between studies of thermal stress. Instead, the most logical and accurate way to measure the thermal environment is also the simplest; recording the thermal climate as fully and accurately as possible in terms of air temperature, humidity, radiative temperature and air movement.

3.4 Recommendations for thermal environments in education

Teaching and learning spaces within universities are not subject to any specialised regulations concerning the thermal environment. Schools are subject to the School Premises Regulations, statutory requirements for environmental provision. The School Premises (General Requirements and Standards) (Scotland) Regulations 1967, and the 1973 and 1979 amendments to those regulations , require heating systems in schools to be capable of sustaining various temperatures according to the type of activity occurring in that space, as shown in Table 3-2. Similar requirements are laid out in the English Regulations (Table 3-3).

Scottish and English regulations specify cold external air temperatures, which are generally associated with wintertime. Both sets simply state the required capability of heating systems, and do not set a requirement for the actual air temperature which is to be maintained.
More generally, the regulations applicable to England and Wales do require that temperatures *"below that appropriate to its normal use, be heated to a temperature which is so appropriate"* , thus avoiding making any specific thermal requirement.

To support and expand upon the School Premises Regulations, in conjunction with Building Regulations, the Department for Education and Skills (DfES) publish a range of Building Bulletins, containing constructional standards for all schools in England and Wales. Building Bulletin 87, the DfES constructional standard for environmental conditions in schools, states that it can additionally be used as a guide to the design of universities, as many of the performance requirements are desirable.

Table 3-2 Scottish School Premises

Activity Level of Area	Temperature (°C) when external air temperature is 0°C
Medical inspection room, changing room, bathroom, WC and shower room	18.5
Teaching space, dining room, nursery room, common room and staff room	17
Assembly area, lecture hall, theatre and cinema	15.5
Sickroom	14.5
Cloakrooms and corridors	13
Gymnasium	13
Games hall	10

Table 3-3 English School Premises

Activity Level of Area	Temperature (°C) when external air temperature is -1°C
Areas where there is a normal level of physical activity associated with teaching, private study or examinations	18
Areas where there is a lower than normal level of physical activity because of sickness or physical disability including sick rooms and isolation rooms but not other sleeping accommodations	21
Areas where this is a higher than normal level of physical activity (for example arising out of physical education) and washrooms, sleeping accommodation and circulation space	15

English and Welsh schools are therefore being designed to sustain winter heating period temperatures of 18°C, and a summer temperature of lower than 28°C (2007), with up to 32°C being allowable in limited instances.

The closest equivalent document to the Building Bulletins in Scotland is the Scottish Executive publication 'School Design: Optimising the Internal Environment'. It aims only to provide advice and guidance for school design and is non-prescriptive. The Building Bulletins are recognised as being frequently used as the basis for Scottish schools briefs, and are acknowledged as providing a good basis for school design. The Scottish Executive does however caution against referring solely to such guidance, emphasising the importance of project specific design. The 18°C winter temperature is criticised for being "considered cold by many users", and summertime performance, even when in accordance with Building Bulletin 101 and Building Bulletin 8, is described as dissatisfactory for some users. The Scottish Executive does however reiterate that the criteria given in the Building Bulletins should be considered as minimum standards, and that design teams should seek to improve the environment beyond them.

Neither set of School Premises Regulations, nor any of the associated Building Bulletins make specific recommendations for humidity levels or air movement in schools, being indirectly addressed by ventilation requirements.

3.5 Temperature and Performance

As defined in section 1.3, three aspects of thermal strain are examined; comfort, mood and performance. This is shown in Figure 3-5.

Various industries have been interested in the general effects of temperature on human performance. Many of the earliest studies were prompted by practical problems encountered during wartime, where soldiers had to undertake sensory, intellectual and muscular work under difficult thermal climates (Mackworth). The work of Mackworth's study in 1950 on the effects of temperature on watch keeping ability of soldiers has been identified as the foundation of modern research (Hancock 1986).

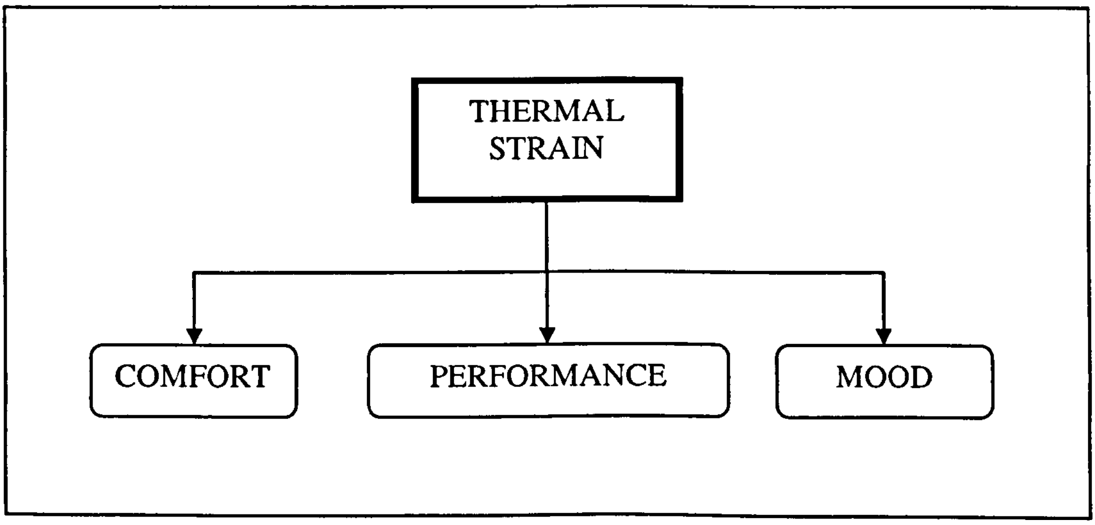


Figure 3-5 Non-Physical effects of temperature

Industrial researchers have also had a historic interest in temperature effects, as factory workers have historically been exposed to extremes of hot or cold caused by industrial processes and machinery. As the nature of industrial employment shifts to non-physical tasks, rather than physical labour, so has the focus of industrial research (Hancock and Vasmatzidis 1998).

Making a generalised statement about the effects of temperature on performance is complicated by a variety of factors. Research over the years has used a variety of indices and units to measure the thermal environment, making comparisons between environments difficult. In addition to these problems researchers are frequently interested in different parts of the temperature scale, and many pieces of research examine the effects of 'hot' or 'cold' in comparison to more neutral temperatures rather than examining a complete temperature range.

Studies of temperature and non-physical performance tend to be laboratory based, where subjects complete a number of tests under thermally controlled conditions. Different types of performance test are used according to the particular interests of the researcher. Relatively little new data has been generated since the 1980's in the field (Ramsey and Kwon 1992), which has prompted several literature review papers to attempt to gather together these disparate pieces of research. Mixed conclusions have been drawn as to the effects of temperature on non-physical task performance.

Pilcher, Nadler et al. (2002) has addressed this problem by conducting a meta-analysis, a mathematical method of averaging previously published studies. Using the results of 22 studies, Pilcher found that temperatures below 18°C WBGT resulted in a large negative effect on performance on reasoning, learning and memory tasks, and exposure to environments of 26°C WBGT or above result in a small improvement. Attentional and perceptual tasks were more negatively affected by temperatures above 26°C WBGT, than temperatures below 18°C WBGT. Mathematical and reaction time tasks are affected similarly to attentional and perceptual tasks. When the results for all types of test are plotted against temperature, a clear inverted-U shape is evident (Figure 3-6).

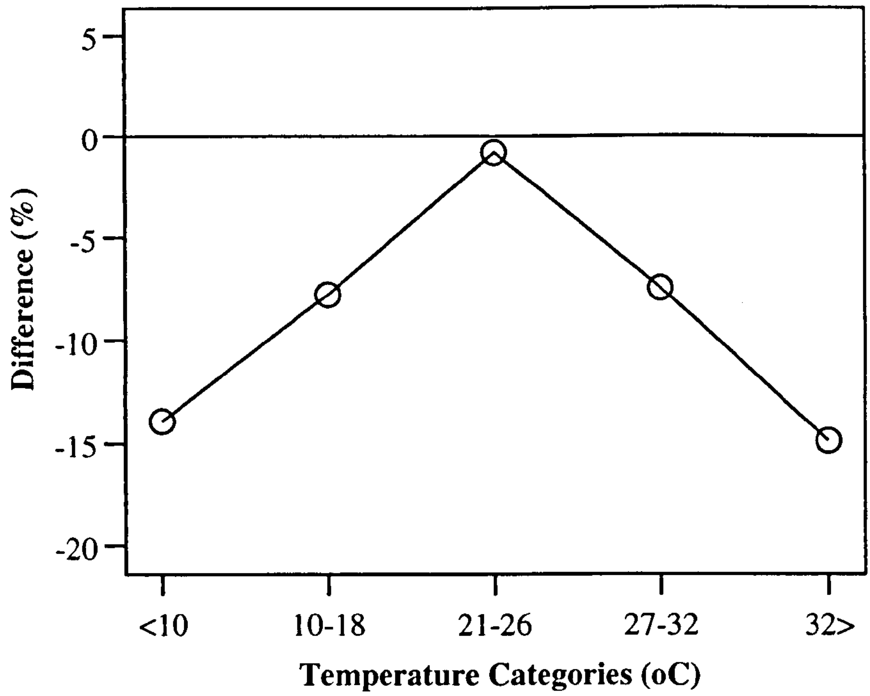


Figure 3-6 Temperature and Performance, Pilcher (2002)

One of the studies sampled by Pilcher was by Griffiths and Boyce, who were interested in warm temperatures. Performance declined at either side of approximately 18°C in a range of about 15 to 27°C, broadly concurrent with Pilcher's overall conclusion. However, Griffiths measured another increase in performance between 24 and 27°C. Given Pilcher's method of categorising temperatures, such an increase can not be reflected in her results. Griffiths suggests that this second increase under slight heat stress could be attributed to the Yerkes Dodson principle, where the increased temperature acts as a stimulant for arousal, and performance is increased.

Griffiths also found there to be more of a correlation between temperature and performance than between assessments of thermal comfort and performance. This leads Griffiths to conclude that comfort is not necessarily a correlate of performance. This is a particular interesting hypothesis in the context of environmental specifications for educational spaces discussed earlier, as the traditional objective of design is to provide a level of comfort, which is assumed to result in better performance.

Ramsey (1995) attempted to compare a range of studies using a graphic approach. Ramsey found that tasks requiring perceptual motor skills appeared to show the onset of a statistically significant decrement in the 30 to 33°C WBGT range. An earlier study by the same author had arrived at the same conclusion (Ramsey and Kwon 1992). These results differ slightly from Pilcher, where decrement occurs earlier.

Enander (1987), who was more concerned with the effects of cold, conducted a pair of experiments using a colour word vigilance task and a digit classification task as cognitive performance tests. After increasing the difficulty of the colour word vigilance task, Enander found that subjects made more errors in the cold condition of 5°C than in the more neutral 21°C condition for both tasks.

These associations between heat and poorer performance have been noted since the early days of performance research, with Bell and Provins proposing that this could be related to feelings of sluggishness and fatigue lowering concentration, and feelings of irritability and discomfort creating distraction from the task. Bell also reports that exposure to hot experimental conditions can result in temporary increases in performance, described as an incentive effect. In view of Griffith's study, it is perhaps more accurate to describe this increase in terms of an increase of performance due to the increased arousal created by thermal stress.

3.6 Discussion and conclusions

This chapter has outlined the nature of the thermal environment, ways of quantifying it and its effects, both physiological and psychological, on humans. This has enabled a model of thermal stress and strain to be constructed, as illustrated in Figure 3-7 below.

The thermal environment is composed of four variables, and it is accepted that all four must be measured in order to describe a climate. Many attempts have been made to create indices for measurement which takes into account the overall effects of these variables, but none have come into everyday use. This has created particular problems for the investigation of the effects of temperature on human performance, as researchers have used a variety of methods to quantify temperature, making direct comparisons between studies difficult.

Building standards and regulations for educational premises have taken a very different approach, defining the thermal environment in terms of air temperature alone. This approach, whilst using a variable which is very easily and cheaply measured, gives an incomplete description of what the thermal climate will feel like to the inhabitants. However, in order to make sure that the results of this research are directly applicable to the way that climate in classrooms is described, air temperature must be the primary climatic variable under investigation. This necessitates the control of the other three variables in experimental work. Conducting testing session in a closed chamber is necessary to eliminate draughts, controlling air movement, and control for the effects of radiative heat. Humidity must be measured during each testing session, as it has previously been mentioned that it can affect performance as an environmental variable in itself.

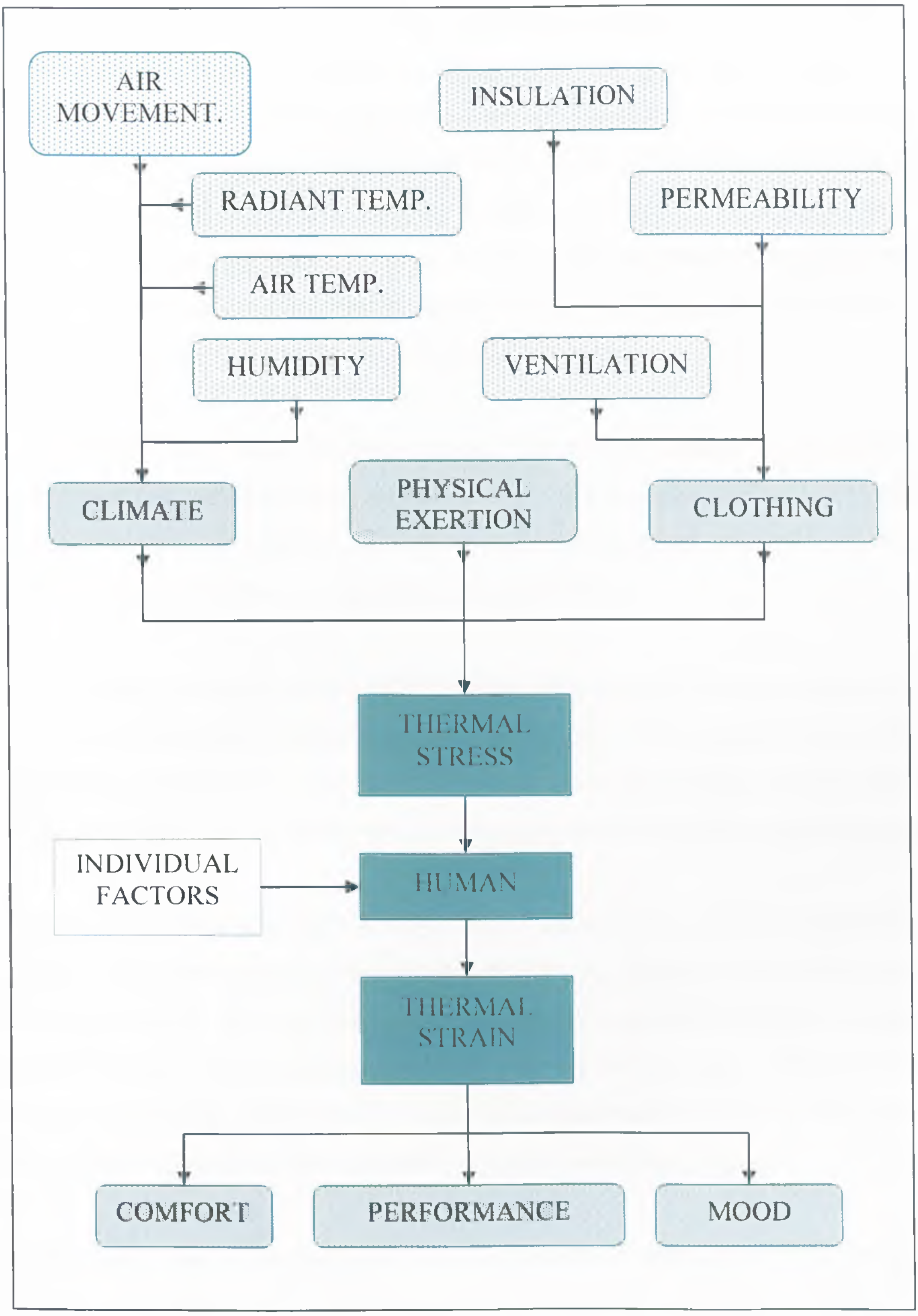


Figure 3-7 Thermal stress and strain, based on Morris (1995)

Previous research has shown that length of exposure and acclimatisation to a thermal condition is an important factor for task performance. This is an important difference when the differences in timetabling between the typical primary school pupil, secondary school pupil, and university student are considered. Primary school pupils are most likely to be allocated the same classroom for the whole school year, and as such will acclimatise, lessening the potential effects of temperature on performance. Secondary school pupils and university students will typically move between different rooms throughout the day, sometimes spending less than an hour in the space. They are therefore more likely to be affected by thermal climate in teaching spaces.

To replicate the short exposure time university students' experience, experimentation should be brief, not taking longer than a typical lecture. Subjects should also not be acclimatised, and performance testing should commence shortly after entering the chamber, to replicate working routines.

Generalisations about the effects of the thermal environment on task performance have best been made by Pilcher's meta-analytic review. The resultant inverted-U relationship between the thermal environment and performance shows that temperatures close to those described as neutral produced better task performance.

Studies such as Bell and Griffiths' imply that conditions that can be described as hot can cause a temporary increase in performance, in adherence with the Yerkes Dodson principle. It is unclear whether this increase in performance is greater than the increase in performance measured at neutral temperatures. Whatever the outcome, enhancing performance by means of a comfortable thermal environment should be considered the more desirable method of aiding performance.

School pupils, and by extrapolation, university students, will typically be exposed to a range of temperatures between 15.5°C and 32°C in classrooms and lecture rooms, proving the range of temperature for investigation. Findings from previous research suggests that 15.5°C may be slightly too cold for optimum performance, and 32°C is likely to be detrimental to performance.

Chapter 4: The Lit Environment

4.1 Introduction

The majority of indoor environments used for the everyday activities of modern life, such as working, studying, eating and relaxing, make use of artificial lighting to supplement or replace natural lighting. A wide variety of lighting provisions are available to match to the requirements of a particular space in terms of architectural design, task requirement, energy expenditure and cost.

A substantial body of research exists examining the visual effects of both natural, and the various types of artificial light, on the occupants of spaces. The results of such research have been used for a wide variety of requirements and recommendations for lighting. Such guidelines ensure that lighting levels are sufficient for the visual demands of the task, as well as reducing the likelihood of accidents caused by inadequate lighting or physical harm such as eyestrain. The CIBSE standard reference on lighting design, the Code for Lighting (2002), provides a definition of the functions of interior lighting as follows:

> *"a) Ensure the safety of people in the interior*
> *b) Facilitate the performance of visual tasks*
> *c) Aid the creation of an appropriate visual environment"*

This definition does not include the non-visual effects of lighting. Lighting can be considered to be an environmental stressor, in the same manner as temperature and background noise; there is therefore a basis for the suggestion that lighting may also have some impact on other non-visual functions, such as mood and cognitive performance.

Many designers of retail and service areas will pay special consideration to lighting provision and its effects on human perception and behaviour. In hotels, for instance, the all important first impression of the establishment is formed by the hotel lobby, and it is this impression which drives the decision of whether to stay or not. It has been found that the importance of the lighting scheme in creating this impression is preceded only by colour and style (Countryman and Jang 2006).

In retail, the term 'sensory atmospherics' describes the qualities of retail spaces that have been designed to evoke a particular consumer response (Sharma and Stafford 2000), of which lighting is a significant component. Customers are for instance more likely to examine and handle goods on a lit display stand, as well as buy the product, than they are on a conventional unlit stand (Summers and Hebert 2001) illustrating one way in which lighting can affect behaviour. If lighting is able to change people's perceptions of a space, then it is reasonable to hypothesise that lighting prompts behavioural or emotional reactions.

This chapter investigates the effect of lighting on sedentary task performance. Methods of measuring the lit environment are outlined, as well as guidelines and recommendations for educational environments. A review of literature examining the effects of lighting on task performance is presented, detailing results and methodological approaches.

4.2 The Lit Environment

The term "light" is defined by the visual response of humans (Boyce 2003), and is the part of the electromagnetic spectrum visible to the human eye, covering the wavelength range from approximately 380 nm to 780 nm (Wiltshire 1997). The human eye discriminates between different wavelengths in the visible range through the sensation of colour. The sensitivity of the human eye is not uniform across the visible spectrum, and varies with wavelength.

Lighting in most modern interiors will be composed of a mix of natural and artificial light, with the emphasis placing on maximising the use of natural light.

This is due to natural light being regarded as more desirable, both aesthetically, and for physiological reasons.

4.2.1 Natural Light

Natural illumination is produced from the sun, either directly, or after reflection from the moon. Daylight can be divided into two components; sunlight and skylight. Sunlight is light received directly from the sun reaching the Earth's surface, characterised by strong, sharp edged shadows. Skylight is light received after scattering in the atmosphere, and produces weak diffuse shadows (Boyce 2003).

The prime characteristic of natural light is variability, where the magnitude, spectral content and distribution of light vary with time of day, year, meteorological conditions and latitude. Within this variability are certain patterns of predictability for most of the earth's surface, such as darkness at night, and brightness during the day, and the amount of daylight hours over the course of a year.

Circadian Rhythms

The lives of living things are characterised by changes in behaviour that occur regularly over a 24 hour cycle, such as the sleep wake cycle. These rhythms including those of plants are known as circarhythms. There are also seasonal patterns known as circannual rhythms such as seasonal seed germination in plants.

Light entering the eye is a means of modifying the phase and amplitude of the system that synchronises circarhythms in humans (Boyce 2003). Exposing the circadian system to bright light early in the night leads to a phase delay, and bright light presented late in the night leads to a phase advance. The impact of lighting on the circadian system is determined by the amount and spectrum of the light and the timing and duration of the exposure to the light.

The circadian system starts directly with the eye, but unlike the visual system it transmits information to the pineal gland not to the visual cortex. In dark conditions the pineal gland synthesises the hormone melatonin which the bloodstream circulates about the body. The role of melatonin is to synchronise the times at which various physiological activities in the 24 hour cycle should occur. Normally high levels of melatonin are secreted at night and low levels during the day. The presence of light at night suppresses melatonin the amount of suppression being determined by the retinal irradiance and the duration of exposure, for up to about one hour (Boyce 2003). Significantly changing the external light/dark cycle requires re-entrainment of the circadian rhythm, which can take days to achieve (i.e. jetlag) (Webb 2006)

The longer the night time the longer is the time that melatonin is secreted. (Boyce 2003) notes that the conception rates of humans exhibited large seasonal variations before it the industrial revolution, and that this could indicate that electrical lighting can have an effect of the seasonal adjustments of the circadian system. The amount of exposure to electric light after dark required to eliminate the effects of naturally occurring seasonal variation in day length is as yet unknown.

Human Function and Daylight

Some argue that all physiological processes function optimally in daylight. The existence of physiological mechanisms that respond to light are taken as evidence for the hypothesis, regardless of the action spectrum for the process, or its relation to daylight (or moonlight) conditions. This theory arises from the evolution of humans in conditions where the sun is the sole source of illumination (see Thorington (1971), Wurtman (1975) and Hughes (1980) in (Veitch and McColl 2001). This is known as the evolutionary fitness mechanism, where "what is natural is good" (Veitch and McColl 2001).

If this hypothesis is correct, deviations in exposure from 'natural' light patterns risks causing abnormal function. A sub-hypothesis of the evolutionary fitness argument is that skin absorption of the UV component of light is physiologically essential to health and well being. (see Ott (1982) and Cameron (1986) in Veitch and McColl (2001)).

Several criticisms of the key assumptions of this theory are made by Veitch and McColl (2001). Firstly, it relies on the assumption that evolutionary pressures on vision and physiological processes selected for optimisation in daylight. Secondly, it assumes that humans cannot adapt to changes in luminous conditions using physiological mechanisms or behavioural mechanisms, as is the case with other environmental conditions, such as temperature.

The idea that day lighting is desirable cannot, however, be completely dismissed. Heschong, Wright et al. (2002) found that the performance of schoolchildren in classrooms with plentiful daylight was better than those with little or none. The results of such studies are complicated by other variables, such as classrooms with windows having a view to the outside world, and the restorative and emotional effects that this can also have.

Most architects will take a middle view of the problem, designing interiors to use as much natural light as possible, supplemented by artificial lighting as necessary (CIBSE 2002). Several models exist which can predict the contribution of daylight to interiors. This study is not directly concerned with the effects of daylighting, but it is important to appreciate its importance to the health of humans, as well as its significance in lighting design.

4.2.2 Measuring Light

Lighting can be described in terms of a number of measurable characteristics, as illustrated in Figure 4-13.

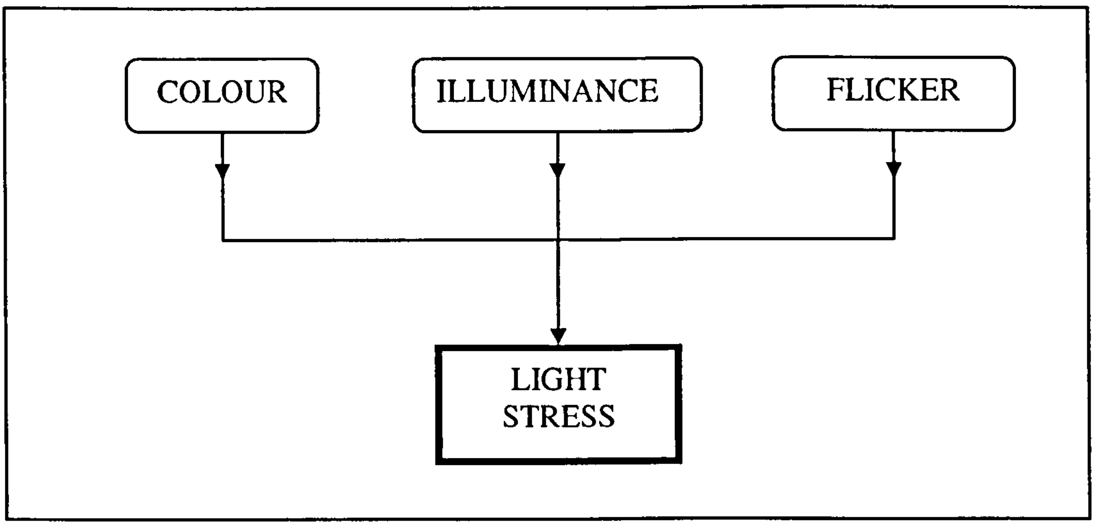


Figure 4-1 Contributors to environmental stress from artificial lighting

These are described as follows.

4.2.3 Luminance and Illuminance

The distribution of light is quantified by luminous intensity, the luminous flux emitted per unit solid angle, in a specified direction. The luminous intensity emitted per unit projected area of a source in a given direction is the luminance, measured as cd/m^2. The luminance of a surface is a correlate of its brightness (Boyce 2003).

Illuminance measures the luminous flux falling on a unit area of a surface, measured in lm/m^2 or lux (Wiltshire 1997; Boyce 2003). The illuminance incident on a surface is the most widely used electric lighting design criterion (Boyce 2003).

The illuminance on the Earth's surface produced by daylight can cover a large range, from 150,000 lux on a sunny summer's day to 100 lux on a heavily overcast day in winter. Due to this variability even rooms with large amounts of natural light will usually require supplementation by electric lighting, especially if they are to be used at night.

The CIBSE standard reference on lighting design, 'The Code for Lighting', gives recommendations for illuminance based on the visual processing requirements of the task being undertaken. Table 4-1 shows examples of various recommended illuminances by visual requirement for different healthcare functions.

Table 4-1 Recommended illuminance for healthcare activities

Area	Function/Task	Maintained Illuminance (lux)
Ward	Night lighting, observation	5
General	Waiting rooms	200
Ward	Examination and treatment	1000
Dental Practice	Operating cavity	5000

The recommended illuminance increases with the visual demands of the tasks to be conducted in that area, so recommended illuminances for demanding tasks, such as operating, are far greater than illuminances required for areas such as waiting rooms.

4.2.4 The Colour of Light

The colour of light is dependant on the combination of wavelengths arriving at the eye of the viewer. Wavelength of light is not associated with luminance and illuminance; different light sources with the same luminance and illuminance may still appear as different colours. As the colour of a light source is based on a process of perception by the observer (Halstead 1997) it should be noted at this point that techniques for quantifying colour, whilst necessary, will not necessarily agree with all subjective observations.

This section describes the quantification of the colour of light, as a series of research studies have been conducted into the colour of light and mood, most notably the work of Knez (Knez 1995; Knez and Enmarker 1998; Knez and Kers 2000; Knez 2001) who investigates various non-visual effects of fluorescent lighting colour type.

Correlated Colour Temperature is the most frequently used measure of light colour (Boyce 2003). Correlated Colour Temperature is a one-dimensional metric of the colour appearance of the light emitted from a near white light source and is convenient and easily understood. Two principles form the basis for quantification of colour of light sources using colour temperature; incandescence and black body radiation, explained as follows.

The sun emits light by glowing at temperatures around 6000 K. All solids, liquids and gases will glow in a similar manner if sufficiently hot such as particles of carbon in a flame at about 2000 K, or tungsten in a lamp at about 3000 K (Wharmby 1997). This glowing of hot bodies is known as incandescence. One of the most important features of incandescence is a colour change as the temperature of the radiator increases, from red to orange to yellow then white and then blue.

This principle of visible colour change in incandescence can be applied to black body emission. A black body, or full radiator completely absorbs all radiation falling on it, and the spectral power distribution is determined solely by the temperature. This means that it is possible to deduce the temperature of an object operating as a black body by its spectral distribution, and vice versa. Planck in 1901 theoretically derived the continuous spectral distribution of the radiation emitted by black body radiators (Wiltshire 1997). This allowed spectral power distribution curves for full radiators at various temperatures to be used to calculate colour coordinates to be plotted onto a chromaticity diagram. They lie on a smooth curve called the full radiator, or Planckian, locus (Figure 4-2). The lines running across the locus are iso-temperature lines, where all chromaticities have the same Correlated Colour Temperature (Halstead 1997).

When the chromaticity coordinates of a light source lie directly on the full radiator locus it is said to have the same Colour Temperature as that particular full radiator, even although Spectral Power Distributions may differ (Halstead 1997).

For light sources with chromaticity coordinates close to the locus but not on it, and within the range of the iso-temperature lines, the colour appearance is quantified as the Correlated Colour Temperature (Boyce 2003), describing the temperature of the full radiator whose colour most closely resembles the source (Halstead 1997).

Light sources with chromaticity coordinates lying beyond the range of the iso-temperature lines should not be given a Correlated Colour Temperature. Such lamps will appear greenish is they lie above the locus, or purplish if they lie below it (Boyce 2003).

Nominally white light sources will generally have Correlated Colour Temperatures of 2700 K to 7500 K (Boyce 2003). Lamps with low Correlated Colour Temperatures appear on the warm side of white, such as the incandescent lamp at 2700 K with a yellowish colour appearance, and those with higher Correlated Colour Temperatures appear cool, such as a 7500 K fluorescent lamp, with a bluish appearance.

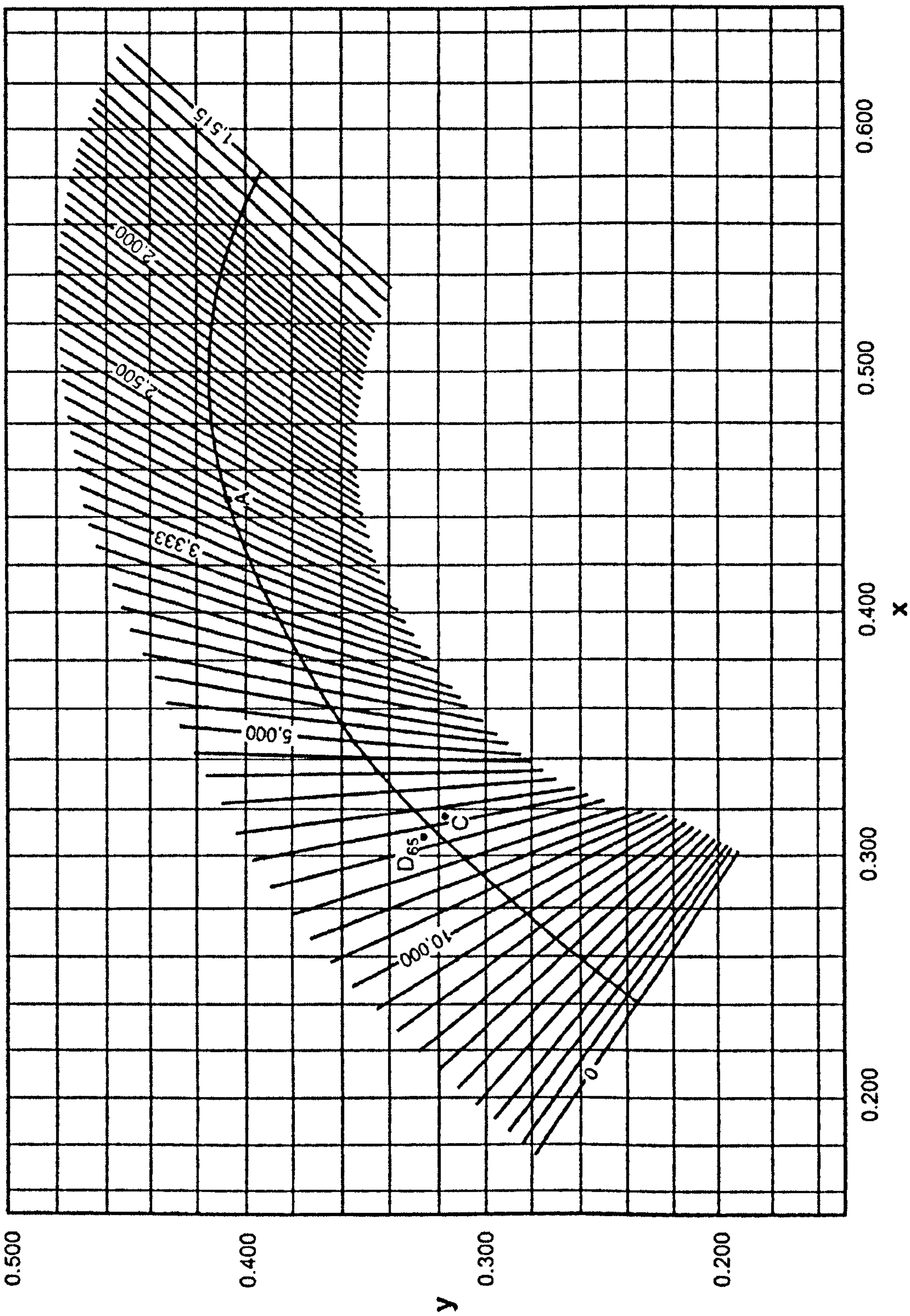


Figure 4-2 Planckian locus, extracted from (Boyce 2003)

Most commonly used fluorescent lamps have Correlated Colour Temperatures of between 3000 K to 4100 K (Boyce 2003), and this perception of a light source having a 'cool' or 'warm' colour appearance is used to categorise linear fluorescent lamps. The Commission Internationale de l'Eclairage (CIE) uses three classes of colour; "warm" at less than 3300 K, "intermediate" between 3300 K and 5300 K, and "cool" at Correlated Colour Temperatures above 5300 K. Some (i.e. Abeywickrama 1997) categorise Correlated Colour Temperatures above 6500 K as "daylight" lamps. Despite such generalisations manufacturers will categorise their lamps differently, and individual Correlated Colour Temperatures should be referenced from product literature.

The Correlated Colour Temperature of daylight varies from 4000 K on an overcast day to as much as 40000 K under clear blue skies (Boyce 2003). As daylight is so variable, there is potential for a discrepancy between the colour of electric lighting and daylight. This can be reduced by using a lamp of an intermediate Correlated Colour Temperature in the region of 3300 K to 5300 K as recommended in the CIBSE Code (CIBSE 2002).

Whereas illuminances are subject to a large number of regulations and recommendations for various types of activities and visual requirements, requirements for Correlated Colour Temperature are less specific. In general rooms with less than 300 lux should be lit using 'warm' colour temperatures (CIBSE 2002).

The colour of the light source will affect the colour appearance of objects and surfaces in the space. White paper viewed under a "reddish" light for instance will take on a pink hue. This effect can be useful and is often used in retail to make food look more appetising, or jewellery more brilliant, but can also be unwanted in tasks involving an element of colour matching. The colour rendering index (CRI) is a measure of the ability of a lamp to depict colours of surfaces accurately. Lamps with a low CRI will distort colours markedly. Tasks requiring accurate colour judgements, such as cooking, or fabrics manufacture, require lamps with a high CRI. CRI is not a measure of direct interest to this study as the type of tasks under investigation will not require colour judgements to be made.

4.2.5 Flicker

The main purpose of lighting is to reduce visual strain and stress in a space which has insufficient or inappropriate natural lighting. Electric lighting is however capable of creating new problems whilst alleviating others. The most relevant of these problems when choosing a lighting type for this study is flicker. In addition to reducing the visual quality of spaces flicker holds implications for mood and performance.

Most lighting installations will be supplied with power by means of an Alternating Current (AC), where magnitude and direction vary cyclically. This produces a regular fluctuation in the amount and spectrum of light emitted. When these fluctuations become visible they are called flicker (Boyce 2003). Flicker is almost universally disliked, unless it is specifically required, and for some individuals such as epileptics, exposure to flicker can be a health hazard (Küller and Lindsten 1992).

The frequency at which an intermittent light no longer appears to flicker is known as the flicker 'fusion' threshold. When the light is bright and diffuse, and stimulates a large retinal area, this threshold can be as high as 90 Hz, but rarely higher (Wilkins, Nommo-Smith et al. 1989).

There is evidence that intermittent light can be still be detected beyond the flicker fusion threshold, whilst remaining imperceptible to the visual system. Studies such as Greenhouse in Wilkins, Nommo-Smith et al. (1989) have found retinal responses to intermittent light at frequencies higher than 100 Hz. Brindley in Wilkins, Nommo-Smith et al. (1989) found that the visual system can resolve frequencies higher than 125 Hz beyond the typical flicker fusion threshold. These studies lead Boyce (2003) to suggest that the flicker threshold cannot be taken as the limit above which intermittent light has the same effect as continuous light.

There are wide individual differences in sensitivity to flicker, and in conjunction with the fact that electrical signals associated with flicker can be detected in the retina even when there is no visible flicker, indicate that a clear safety margin is necessary to avoid discomfort (Boyce 2003).

The probability of flicker can be reduced by ensuring a stable supply voltage and by use of high frequency electronic control gear for discharge lamps. Use of high frequency control gear on fluorescent lamps has been associated with a reduction in the prevalence of headaches and eyestrain (Boyce 2003). Figure 4-3 and Figure 4-4 from Küller (1998) show the differences in luminous modulations between high frequency ballasts and conventional core coil ballasts.

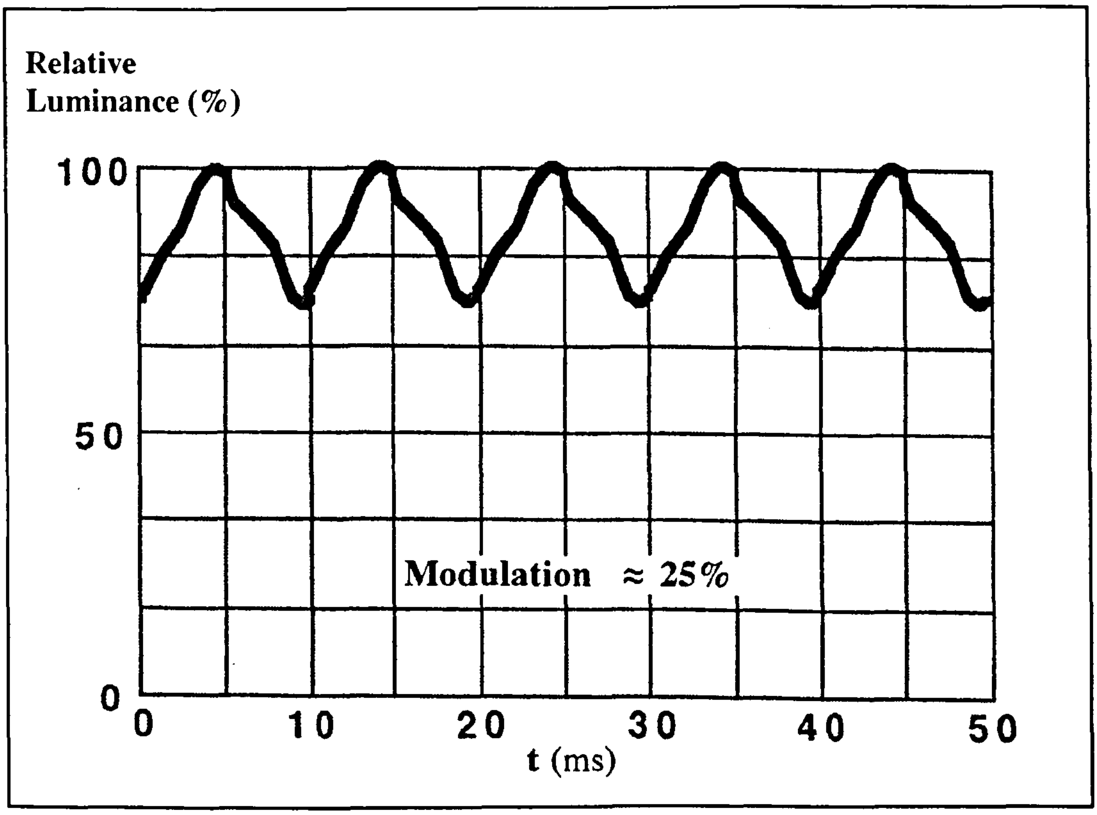


Figure 4-3 Luminous modulation of a high frequency ballast

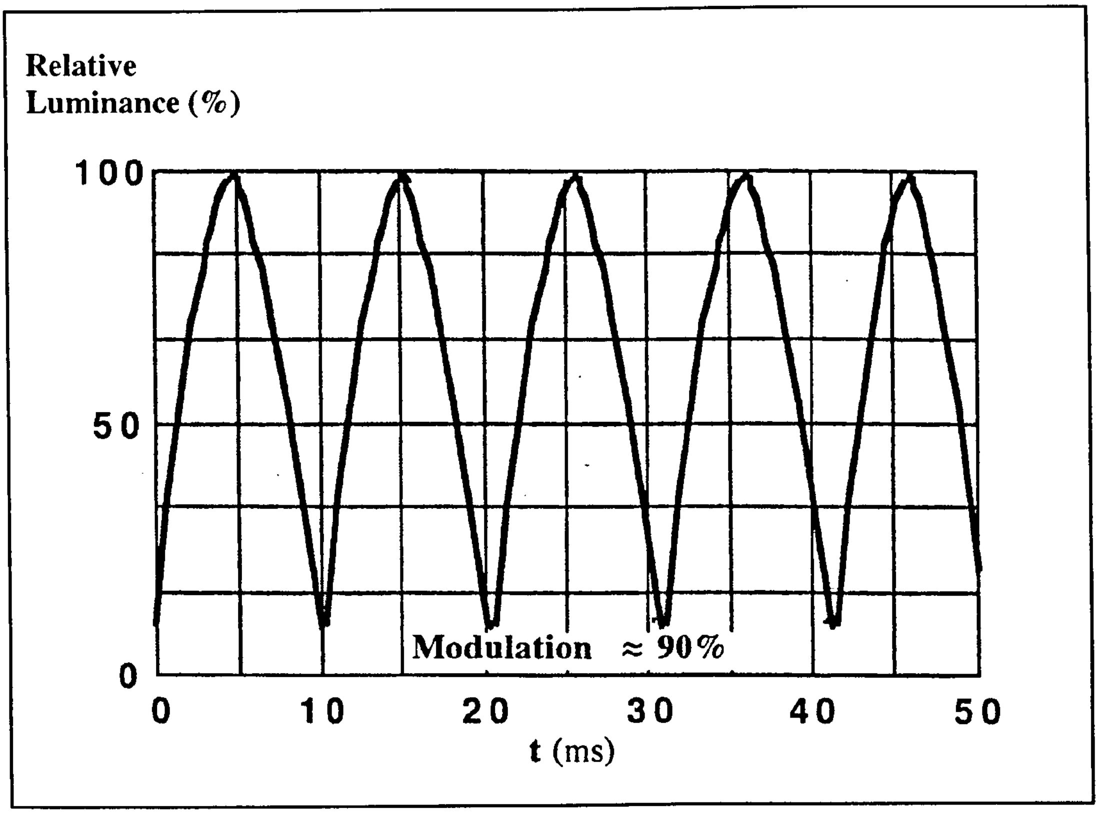


Figure 4-4 Luminous modulation of a conventional core coil ballast

Wilkins, Nommo-Smith et al. (1989) found that use of high frequency fluorescent lighting can reduce such incidences of headaches and eyestrain, theorising that tasks requiring visual scanning of surfaces with spatial periodicity, such as text, under fluctuating light, can cause interaction of spatial and temporal periodicities to interact. This interaction could cause interference with ocular motor control, and cause headaches.

Küller and Laike (1998) suggests that sensitivity to flicker increases with age. As such conventional core coil magnetic ballasts in schools may be inappropriate.

Many students will find themselves being examined in sports halls at some point in their academic studies, which have different lighting requirements to teaching and study spaces. Flicker can create 'ghost images' of fast moving objects, and special attention is paid to this problem in sport hall design where the effect can be minimised through use of lamps and control gear with minimum modulation, such as fluorescent tubes operating on a high frequency electronic gear (Forster 1997). Sports halls are often designed with such specialist provision.

4.3 Artificial Lighting

Interior artificial lighting is generally provided in environments where students may find themselves studying or being examined. In these settings the user often has no form of control over the level or type of light provided. This section describes the properties of the types of lighting provision that students will encounter most frequently; incandescent and fluorescent lighting.

Incandescent lamps

The most common form of incandescent lamp is encountered in the form of the household bulb. The incandescent lamp has been commercially available since the 1880's (Boyce 2003) and is widely used, small, cheap, simple to operate, holds good colour properties and is easily dimmed.

Incandescent filament light bulbs can be directly connected to an electrical power supply without control gear or ballast components. Light is produced by heating a thin tungsten filament to incandescence in an inert gas atmosphere (Boyce 2003).

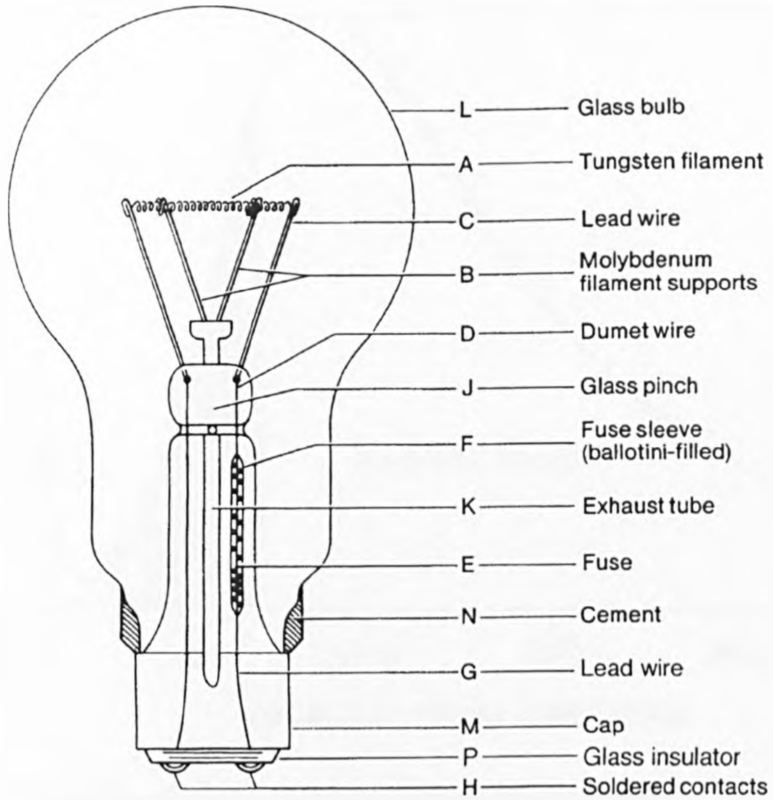


Figure 4-5 Construction of a typical incandescent lamp

Figure 4-6 shows the relative spectral distribution of a typical incandescent lamp. The spectral emission of the incandescent lamp is a continuum over the visible spectrum, with the temperature of the filament determining the exact spectrum (Boyce 2003). Tungsten filament lamp spectra increase towards the red end of the spectrum and have a large infrared output (Howe and Connor 1997). Incandescent lamps peak at longer wavelengths, giving a more yellow light in comparison to fluorescent lamps, and it has been found that undergraduate students prefer the hue of incandescent light (Bartholemew 1975).

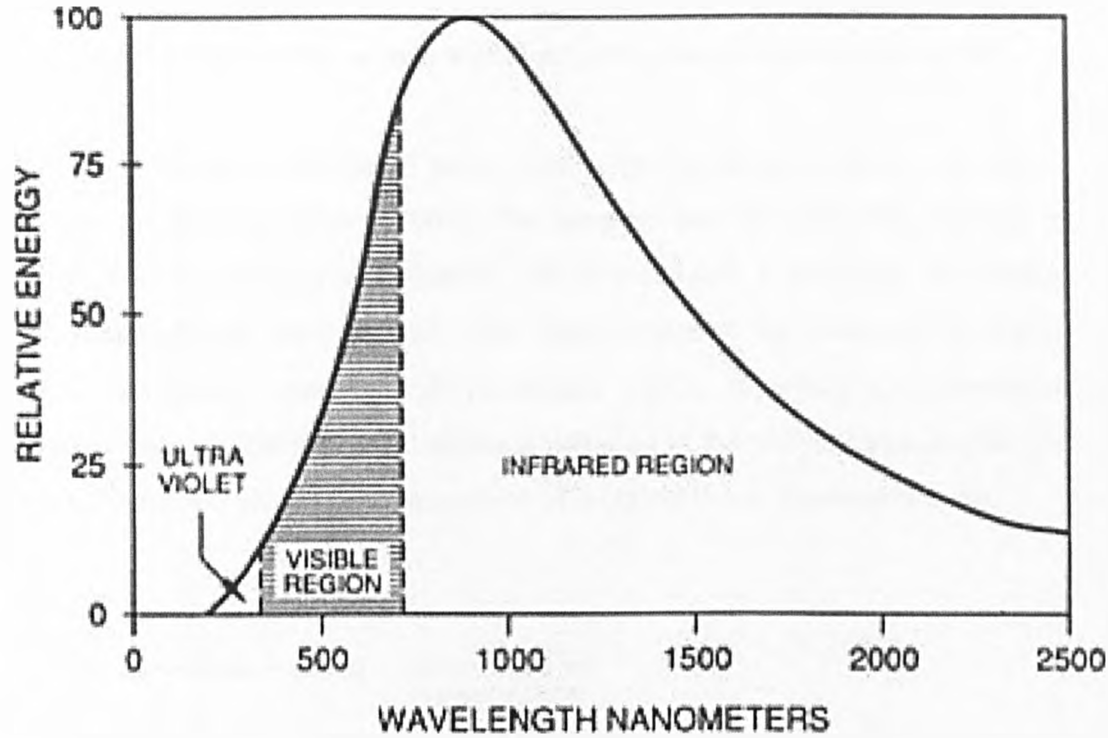


Figure 4-6 Spectral emission of a typical incandescent lamp

Dimming incandescent lamps by turning down the current through the filament and reducing the temperature of the filament results in a reduction in colour temperature, where lamp colour becomes yellow, then red, and then at very low voltages emitting infrared radiation with no visible light.

Incandescent lighting is an acceptable form of lighting for lecture theatres, lecture rooms and teachings rooms (CIBSE 1991), as it is readily controllable in intensity and direction, and aesthetically often preferable, as long as down lighters are not used. The energy usage of incandescent lighting is however inefficient, both in terms of the energy consumed to produce light, and also in respect of additional heat introduced to the space, frequently requiring mechanical removal.

Fluorescent lamps

Fluorescent lamps have been available for use in general lighting schemes since the 1940's and are the dominant artificial light source for industrial and commercial applications. They have become so successful due to their high efficacies, colour choices and long life. Estimates for use of fluorescent lamps are in the region of 80% of the worlds artificial lighting use (Abeywickrama 1997).

Fluorescent lamps are discharge lamps, where light is produced by the excitation of a gaseous discharge (Boyce 2003). The lamp consists of a glass tube containing a low pressure mercury atmosphere, which maintains a discharge of mainly ultraviolet radiation when excited. The inner surface of the glass tube is coated with a fluorescent material (Abeywickrama 1997), absorbing the ultraviolet radiation from the discharge and emitting radiation in the visible spectrum (Boyce 2003). Figure 4-7 shows the construction of a typical linear fluorescent lamp.

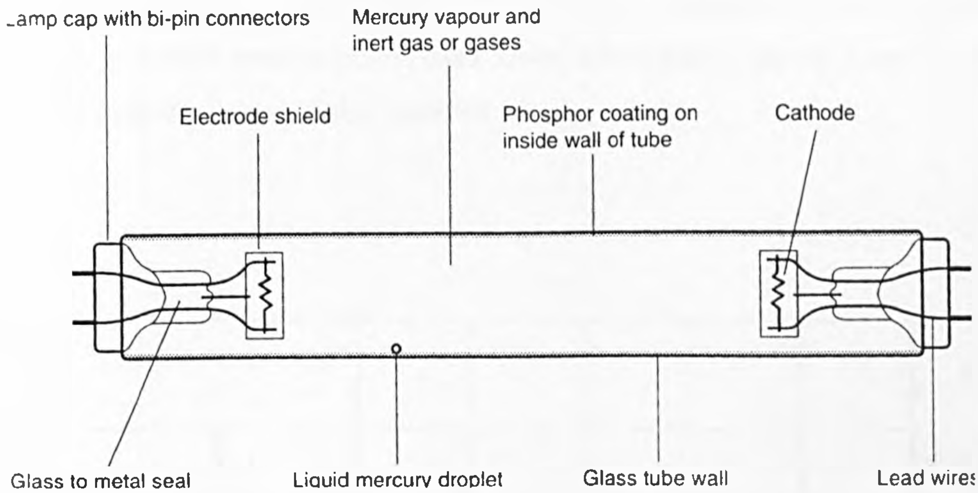


Figure 4-7 Construction of a typical fluorescent lamp

Due to the dual emission process fluorescent lighting produces a combined spectrum, where the continuous emission from the phosphor is combined with the line spectra of the mercury discharge. Continuous spectra will generally produce less colour distortion than a few discrete lines. By changing the phosphor mix different spectral emissions can be created with a range of colour properties. Figure 4-8 and Figure 4-9, extracted from trade literature (OSRAM 2000) show two forms of fluorescent lamp that have different phosphor mixtures, producing two quite different colour appearances.

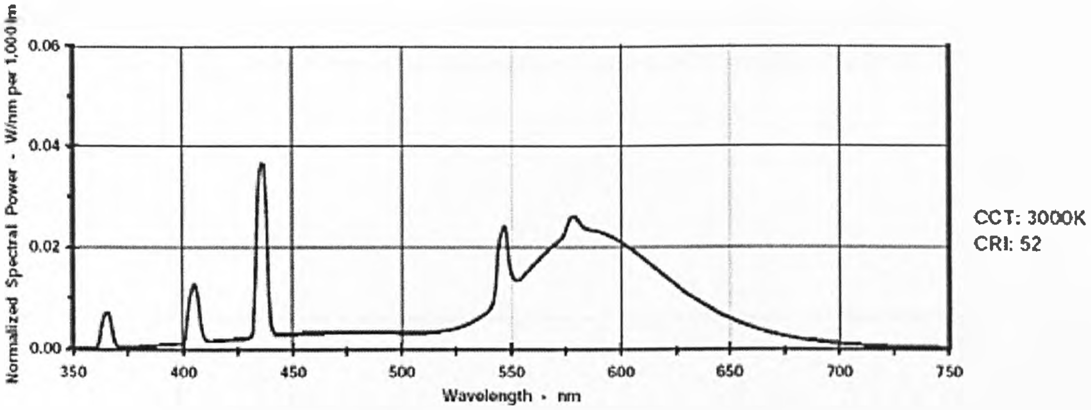


Figure 4-8 Relative SPD of Warm White Fluorescent Lighting

Warm White Fluorescent lighting (Figure 4-8) has more orange and red tones than incandescent lighting and Cool White. Cool White fluorescent lighting (Figure 4-9) has an increased spectral power over lower wavelengths, giving a cooler blue appearance than the Warm White varieties.

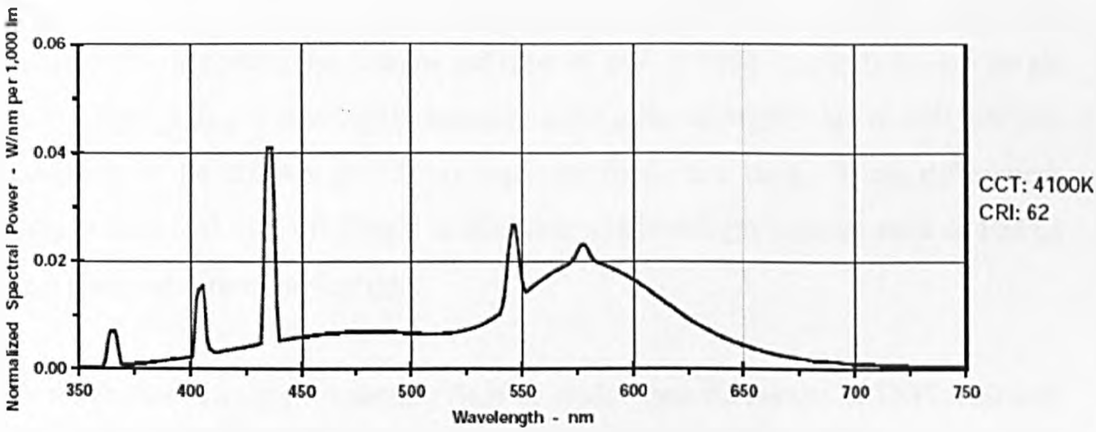


Figure 4-9 Relative SPD of Cool White Fluorescent Lighting

There is currently a research trend investigating the effects of fluorescent lamps which purport to simulate the effects of sunlight, known as Full Spectrum Fluorescent Lamps (FSFLs), on various aspects of performance and mood. Veitch and McColl (2001) report that the similarity between FSFL emissions and daylight is tenuous, although the general shape of the SPD of a FSFL (Figure 4-10) is more similar to daylight than the popular cool white fluorescent lamps. It should be noted that the manufacturer of the FSFL shown below does not claim that their lamps of this type hold beneficial properties, or indeed market them as FSLSs as such.

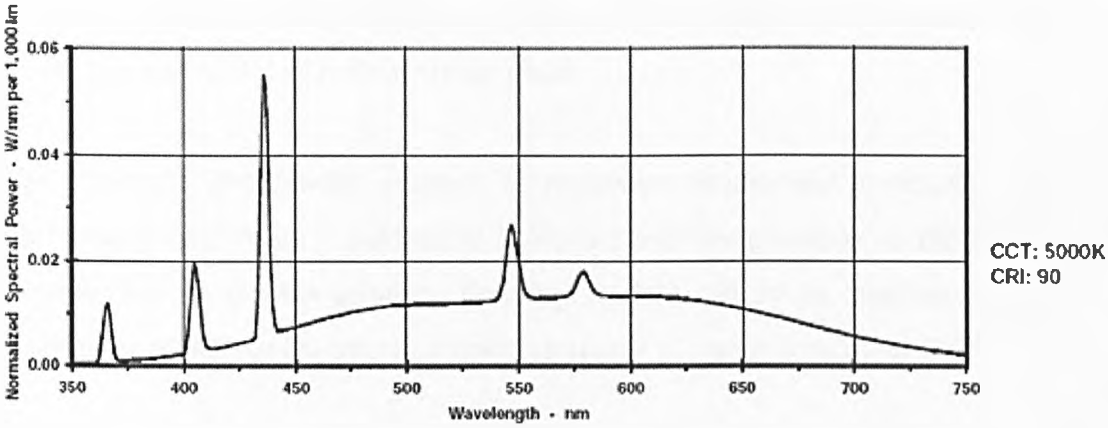


Figure 4-10 Relative SPD of FSFL

There are multiple reasons for the dissimilarities despite the similarities in SPD shape. Daylight varies in colour temperature from 5,000 K to 10,000 K depending on atmospheric conditions, season and time of day. A FSFL can only have a single CCT. Daylighting is also highly intense; in the order of 50,000 lux to 100,000 lux, compared to the 200 lux to 500 lux typically found at a desk. These differences cause Veitch and McColl (2001) to find that artificial light sources such as FSFLs are a poor substitute for daylight.

Although this is a very interesting field of study, specific results of FSFL research are not considered in this thesis, as the effects of such lamps are considered to be outside the scope of this study. Many experiments have however been conducted which use more than one type of lighting in addition to full spectrum light sources. Such studies offering data about mood and performance with relevant data in relation to more traditional lamp types are discussed.

4.4 Recommendations for Lit Environments

The English School Premises Regulations require lighting levels to be appropriate for a space's normal use, with a minimum maintained illuminance of teaching accommodation of 300 lux on the working plane. In teaching accommodation where visually demanding tasks are to be carried out, maintained illuminance is to be no less than 500 lux on the working plane.

The Scottish Regulations require a minimum maintained working plane illumination of 108 lux . Additional Scottish Executive guidance on the internal environment in schools requires Building Bulletin 90 to be used to identify lighting standards for learning and teaching spaces (Scottish Executive 2007).

The Buildings Bulletins emphasises the importance of lighting installations to school design. Figure 4-11, extracted from Building Bulletins 87 and 90 illustrates considerations the design framework for lighting designers in schools. Despite the comprehensive nature of the framework, no provision is made for the psychological effects of mood. Building Bulletin 90 defines maintained illuminance levels for spaces within schools (

Table 4-2).

The Code also gives recommended illuminances for educational buildings and libraries. The areas in which students are most likely to find themselves studying are summarised in Table 4-3. The Code does not make provision for any form of specialised study area.

These recommendations are further supplemented by a Lighting Guide, again issued by CIBSE, for lecture, teaching and conference rooms. This Guide differentiates between larger, generally raked lecture theatres and smaller, generally flat, lecture rooms with a capacity of less than 60 to 80 students, in addition to teaching rooms. The aim of the lighting is to *"reveal the lecturer to the audience and the audience to the lecturer and also to provide for other visual tasks involved".*

There is often provision for lighting in the presenting area of larger, theatre-like lecture rooms, to be brighter than the audience area to enhance the visibility of the lecturer. In such instances the designer must be careful to avoid veiling glare and reflections on projectors or black/whiteboards, whilst providing suitable light for note taking and reading.

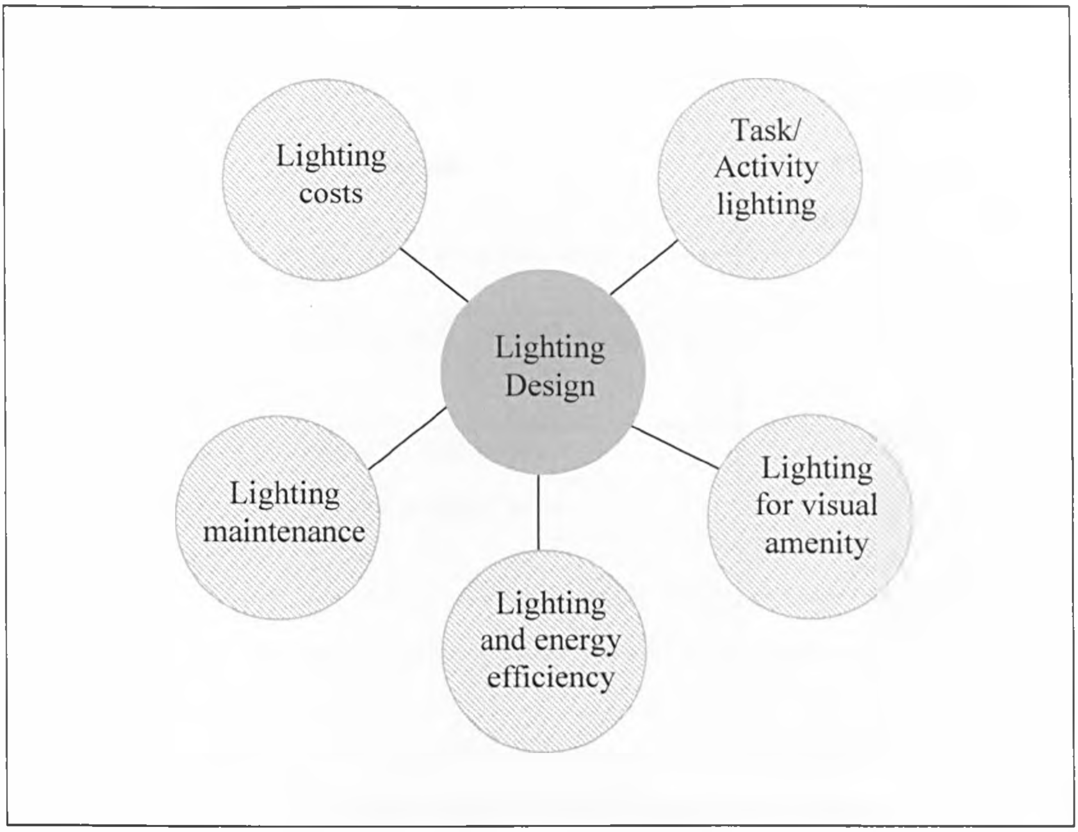


Figure 4-11 Design framework for lighting design extracted from Building Bulletins 87 and 90

Table 4-2 Standard Maintained Illuminance Levels for Schools

Type of Space	Standard Maintained Illuminance (lux)
General teaching spaces	300
Teaching spaces with close and detailed work (e.g. art and craft rooms)	500
Circulation spaces; corridors and stairs	80-120
Entrance halls, lobbies and waiting areas	175-250
Reception areas	250-350
Atria	400

Table 4-3 Recommended illuminance for educational institutions

Area	Function/Task	Maintained Illuminance (lux)
Educational buildings	Classroom/tutorial room	300
	Evening class/adult education	500
	Lecture hall	500
Library	Reading area	500

Minimum illuminances for the audience area of lecture theatres are in the order of 200 to 300 lux. For lecture rooms the audience area at desk level should be a minimum of 200 lux. Teaching rooms where formal instruction is given to students sitting at prescribed places should provide a working plane illuminance of 300 lux. In teaching rooms where group interactive learning is conducted the recommended level is a lower 150 lux. As with the Code, the Guide does not make any mention of lighting provision in specialised study areas. The Library Association advise an illumination of 400 to 600 lux in general library study areas (Rooney 1994).

4.5 Lighting and Performance

The visual effects of lighting have been studied for many years, with the advent of gas and electric lighting in the 1800's prompting research interest in practical lighting applications (Bommel and Beld 2004). The visual effects of lighting have been well researched and form the basis for the wide range of regulations and recommendations for lighting in buildings. The non-visual effects of lighting are less well understood (Figure 4-12).

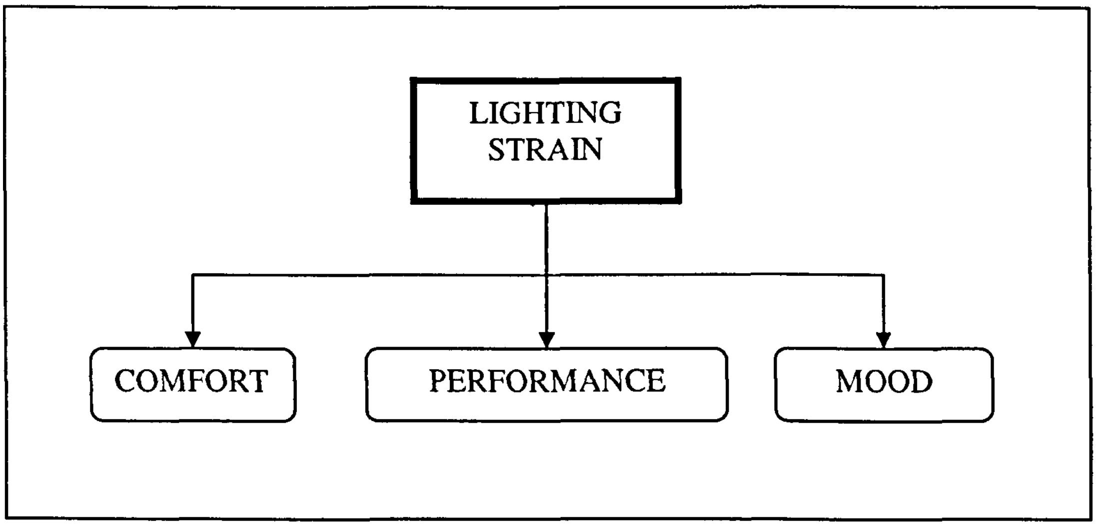


Figure 4-12 Non physical effects of lighting

Research is ongoing across these fields. Most of this research focuses on the effects of fluorescent lamp type, specifically the effects of the spectral distribution on mood and performance (Boray, Gifford et al. 1989; Veitch, Gifford et al. 1991; Knez 1995; Veitch 1997; Knez and Kers 2000). Research concerning working plane lighting level is rarer.

A study by Muck and Bodmann (1961) is revisited by Boyce (2003) to illustrate that lighting conditions that are considered uncomfortable do not necessarily lead to a decrease in task performance. Increased illuminances were linked with increased task performance speed, as well as the percentage of people that considered the lighting "good". As illumination exceeded 2000 lux, however, the percentage of people considering the lighting "good" declined even although mean detection speed continued to increase. The most comfortable conditions are not necessarily the same as those which optimise performance.

More recently, Baron, Rea et al. (1992) investigated effects of working plane illumination level and spectral distribution on decision making. Subjects were given simulated CVs, and asked to evaluate imaginary employees. It was found that subjects in the 150 lux condition assigned more favourable ratings than those in the 1500 lux condition. A secondary task of word categorisation was applied. Respondents were given examples of words belonging to various groups, and asked to rate each word in terms of how much it 'belonged' to that category. Subjects in the lower illuminance condition generally assigned higher ratings to poor exemplars than those in the high illuminance condition. Such results indicate illuminance level can impact mood.

The series of studies by Knez, although focussed on the effects of colour of light are of relevance. An investigation of the combined effects of mood, colour temperature and illumination (Knez 1995), highlights several interesting points. Firstly, long term memory performance was found to be particularly present in the high illuminance condition (1500 lux) in comparison to the 300 lux condition, in a task requiring participants to read a text, and answer a series of questions.

Secondly and perhaps most importantly, is the assertion that best performance is achieved in lighting conditions where positive affect is preserved. Knez continues to investigate this idea, although ceases use of working plane illumination as a variable, primarily due to an interest in the effects of fluorescent luminaire type, rather than illuminances.

Subsequent similar experiments by Knez concerning the effects of the colour of light failed to find an effect on cognitive performance, although it was found to have an effect on mood (Knez and Enmarker 1998; Knez and Kers 2000). This could imply that illuminance level is in fact a more important variable than the colour of the light on performance, although the colour of light affects mood.

Muck and Bodmann's study implies performance increases with illumination. Baron's results suggest that lower illuminations have more of a positive effect on mood than higher illuminations. Taken together these results directly contradict Knez's assertion that increased performance is congruent with more positive moods. However, they agree with Boyce's conclusion that more stressful conditions, which should hypothetically lead to more negative mood, can increase performance.

The literature suggests that investigations of the effects of the spectral distribution of light on mood and cognition are more commonplace than those investigating working plane illuminances. This is a peculiar anomaly, as effects of illuminance on cognition and mood have never been thoroughly researched in order to disprove the existence of such effects, and the limited numbers of previous studies suggest such an effect. In view of the fact that working plane illumination level is one of the primary ways to specify the quality of the lit environment, this is an inconsistency which should be remedied.

4.6 Discussion

The review of literature has enabled a model of environmental stress and strain caused by lighting conditions to be composed as shown in Figure 4-13.

The colour of light is of most interest to the scientific community. Regulations and recommendations for classrooms tend to be more focussed on working plane illuminances. As a result, there is little direct knowledge of the non-physical effects of illuminances found in classrooms.

Flicker has been highlighted as an important contributor to environmental stress created by lighting. As the focus of this research is illumination, the occurrence of flicker during experimentation must be controlled. The most effective method is to use incandescent bulbs, which have the additional advantage of dimming capabilities allowing a range of different illuminances to be produced from the same lighting set-up, unlike fluorescent lamps.

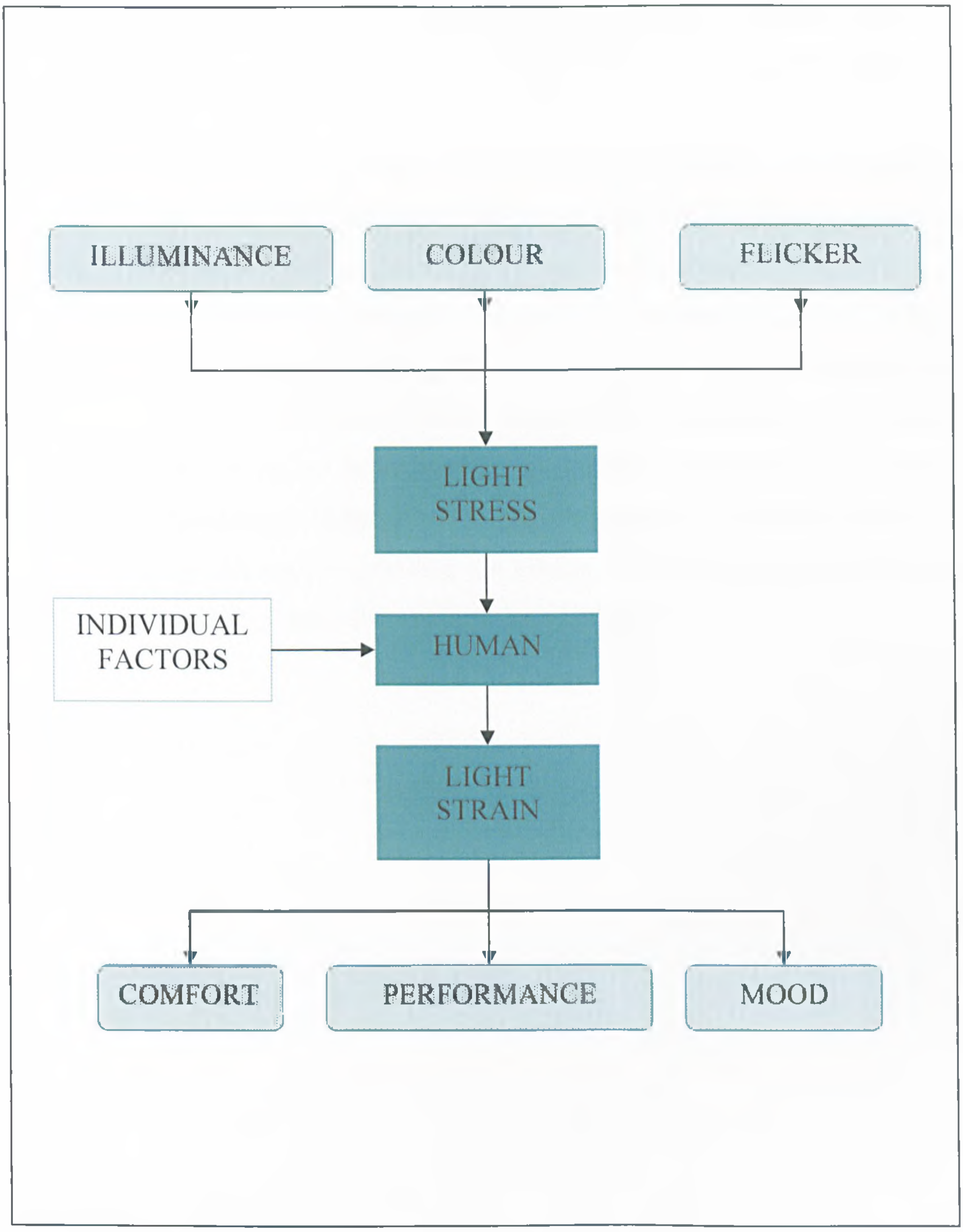


Figure 4-13 Lighting stress and strain, based on Morris (1995)

Research into the effects of the lit environment is centred on the effects on mood and cognition. Interest is primarily directed towards the effects of the various types of fluorescent lighting, and the effects their colour may have on the occupants of a room. Emphasis on working plane lighting level appears to be for the purposes of visual acuity, rather than any effects on mood and performance.

Surprisingly little research has been conducted using illuminance as a measure of light, with researchers preferring to investigate colour. When lighting provision in schools is compared with to the limited performance research available it is apparent that the low illuminances detailed in publications such as School Premises Regulations and Building Bulletins may be more comfortable for occupants. Larger illuminances have the potential to improve performance, although the precise means by which this increment is achieved is a matter of debate. As working plane lighting level is the main way in which the environment is defined, there is a need to establish the effects of various illuminance on task performance, as well as further investigate mood effects.

Chapter 5: Interaction of Temperature, Lighting and Noise

5.1 Introduction

The previous three chapters have described the individual effects of temperature, lighting and noise on task performance. This format reflects the way in which researchers have generally investigated the effects of a single variable in isolation. This does not reflect reality, where the environment is more complex.

A variety of trade-offs are made in the design and use of buildings. Maximising daylight in the design of a building, for instance, can also result in an increase in temperature through solar gain. Opening a window to increase thermal comfort can result in increased noise transmission from outside. Krüger and Zannin (2004), found that opening the windows of a Brazilian university classroom caused an increase in the region of 10 dBA, which corresponds roughly with a doubling of perceived loudness. Using air conditioning could also be a potential source of noise in the classroom.

Noise, thermal climate and lighting have different effects on performance and mood, and also some common attributes, suggesting that the interactions of environmental variables will be complex.

There is a body of theoretical research available, mainly concerned with possible outcomes of interactions, which is presented and discussed. Only a limited amount of laboratory research has been directed at examining the effects of interactions between multiple environmental variables on performance. The results of these studies are discussed, and are used to highlight methodological problems.

5.2 Theoretical Basis for Interactions

Where univariate studies have generally been interested in ascertaining the type and extent of effect that an environmental variable may have on performance, multivariate studies have a more complex background. The theoretical basis for the interaction of stresses was formed by Broadbent in the 1960's and early 1970's. The principles of his work as well as subsequent interpretations of it are discussed as follows.

Broadbent was the first to consider the means by which stressors interact, in 1963. Previous research, i.e., Pepler (1960), Mackworth (1950), had ascertained that different stresses affected task performance in different ways, but the idea of interactions had not yet been addressed.

As a psychologist, Broadbent was interested in understanding the 'mechanism' by which the effects of environmental stress are produced, proposing that different stresses would either affect different mechanisms, or affect the same mechanism to different extents (Broadbent 1963). These ideas were prompted by studies of heat, noise and sleeplessness, but the principles are applicable to all stressors.

By 1971, Broadbent had further developed these ideas in terms of outcomes. He proposed that if two stresses, both causing impairment, acted on different mechanisms that each should produce its effect independently, i.e. simple additive or subtractive effects. If the stresses affect the same mechanism then an interaction occurs, where more drastic impairments are likely, i.e. synergetic effects (Broadbent 1971). These ideas of Broadbent's have formed the theory and vocabulary of interaction effects, and have sometimes been misunderstood.

Grether, Harris et al. (1971) for example, interested in the effects of heat, noise and vibration stress, discusses the interactions of different mechanisms, writing:

"...a combination of two stressors with antagonistic mechanisms, such as depressant and stimulant might cause less impairment than either stressor alone".

Grether is suggesting that it is the mechanisms that are antagonistic. This is a misunderstanding of Broadbent's idea of two stresses having an antagonistic effect on the same mechanism.

Broadbent's work has remained central to studies of interactions. Hygge (1991), for instance, returns to the idea of mechanisms to investigate the interaction of noise and heat. He generalises that:

"Two stressors affecting the same psychological mechanism should yield an interaction, whereas two stressors affecting different mechanisms should not".

Such statements show little departure from Broadbent's ideas as presented in the 1960's and 1970's. There is a general consensus that two stresses acting on the same mechanism results in an interaction, which may be synergetic (greater than the sum) or antagonistic (less than the sum). Where stresses act upon different mechanisms, no interaction occurs, and the overall effect is simply parallel, additive or subtractive.

5.3 Multivariate Research

One of the earliest examples of multivariate research is the work of Pepler. By 1960 it had been fairly well established that unusually warm atmospheres cause deterioration in the performance of a number of tasks, but there were concerns as to whether:

"the reported decrements in efficiency were in fact due to the level of warmth, or merely to the general strangeness of abnormality of the condition" Pepler (1960).

To address this, Pepler (1960) compared the effects of heat with the effects of glare and a potentially distracting noise on a pursuit tracking task.

Pursuit tracking tasks are tasks of perception, where subjects manually align a pointer with an erratically moving target. Integrated errors over time are measured, as are the number of times that the pointer reverses its direction of movement in excess of the number of reversals of movement of the target. High numbers of pointer movements indicate that subjects are making additional movements to correct inaccuracies in their primary movements.

It should be noted that in this type of test high error scores can also be achieved by a respondent not doing anything, as opposed to other types of test, where the respondent has to do something to make an error.

Pepler used two temperature conditions; normal (air temperature of 21°C and wet-bulb thermometer reading of 18°C), and warm (38°C with a wet-bulb reading of 32°C). Glare was provided by means of placing a naked 100 watt tungsten filament lamp beside the test apparatus. Aural distraction was provided through a single earpiece, consisting of a woman's voice reading a descriptive passage from a thriller at a low intensity, so that speech was only just audible.

Two experimental groups were used by Pepler, each consisting of twelve Royal Navy sailors between 18 and 25. Both groups were set the tracking task for 40 continuous minutes daily, for five consecutive days. The order of testing for temperature conditions varied between the halves of each experimental group (Figure 5-1). Results from the first day of testing were not used in the analysis. Results showed an increase in the number of pointer movements in warmth.

Six participants:	21°C	38°C	38°C	21°C	21°C
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
Six participants:	38°C	21°C	21°C	38°C	38°C

Figure 5-1 Temperature schedules for both halves of each experimental group

The first and second experimental groups were exposed to glare and noise respectively, for the middle 20 minutes of each work period. The first and last ten minute segments act as a control between groups. The daily session schedule is shown in Figure 5-2.

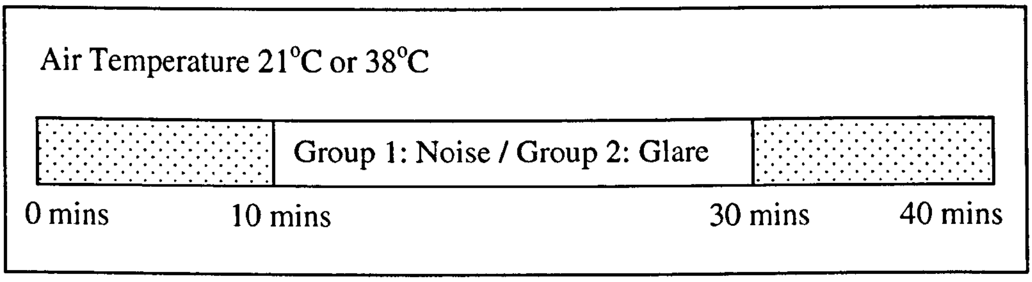


Figure 5-2 Daily session schedule

A significant difference in performance between the first and last ten minutes of a session was found. Both an increase in the number of alignment errors, and a decrease in the number of pointer movements, was measured. This overall decrease in quality of performance between the beginning and end of a session is labelled by Pepler as being a "fatigue or time effect".

Making the assumption that this effect is linear allows Pepler to superimpose the results from the middle of the sessions onto the predicted performance decrement. Figure 5-3 show the results for both experimental groups. Performance during glare and noise conditions is significantly worse than during either control condition.

Pepler interprets this part of his results to mean that glare and noise make subjects "less ready to notice or less able to see the inaccuracies of their tracking movements", therefore making fewer corrections and achieving lower scores.

However, the patterns of performance in Figure 5-3 are reminiscent of the inverted-U shaped curves discussed in previous chapters. Performance in the middle tests could indicate a peak of boredom or fatigue, rather than effects of glare or speech.

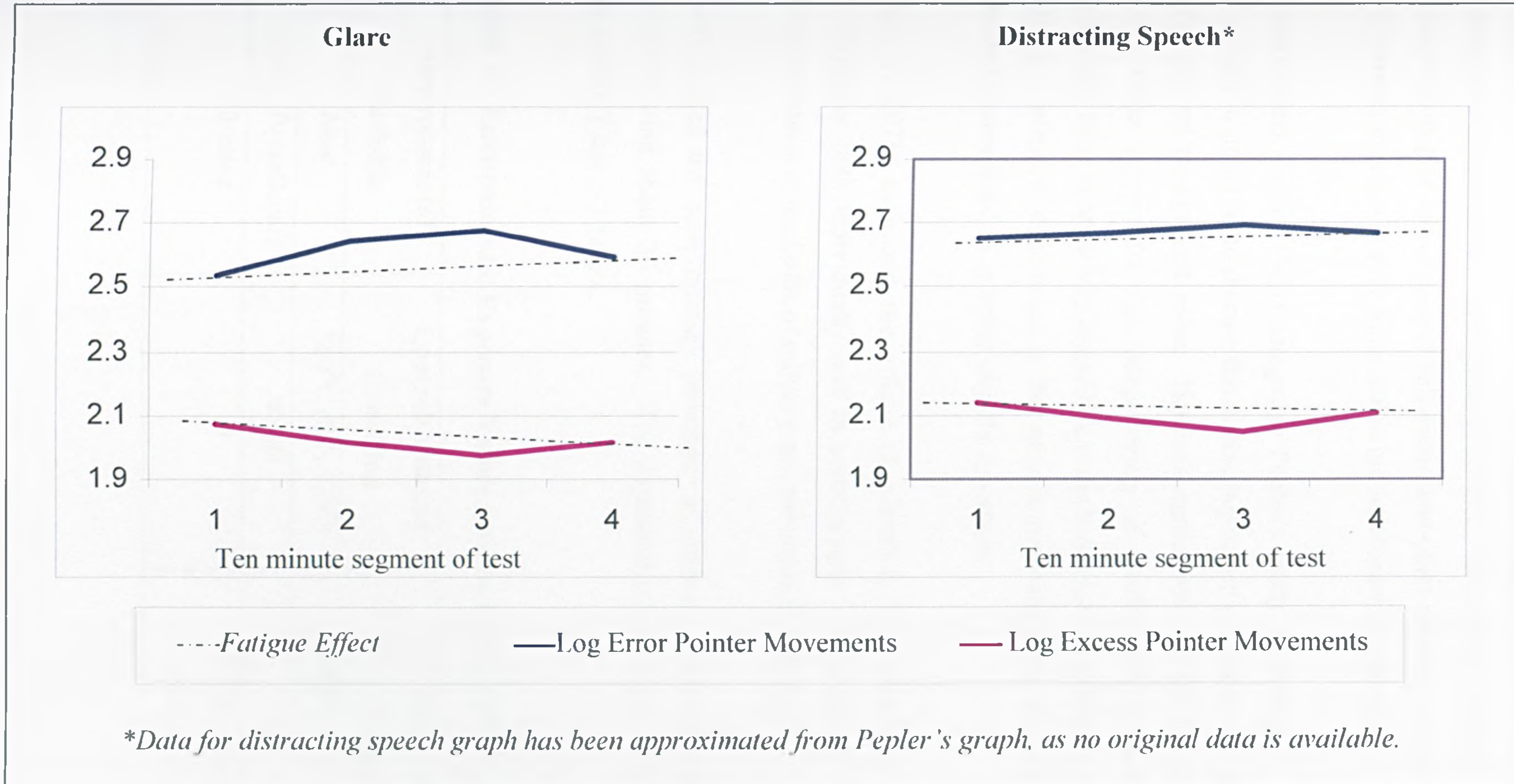


Figure 5-3 Graph of the effects of glare and speech on the accuracy and frequency of pointer movements

Pepler's study has been cited many times. Broadbent (1963) uses it to demonstrate differing patterns of behaviour under different stresses, where distractions interfere with perceptual processes. Broadbent concludes that some stressors will give inert types of behaviour, and other stressors, such as noise and high temperatures, will give more active but inaccurate performances.

Hancock and Pierce (1985) categorise Pepler's study as finding a "negligible" noise effect, going on to discuss the distracting nature of speech, in comparison to more general background noise. Hancock agrees with Broadbent that the study offers some support for the independency of thermal and acoustic stressors, describing them as relatively insensitive to each other, but cautions against treating this as a definitive conclusion to the subject, recommending that noise and heat should be considered to as being slightly synergetic.

Grether (1971) examined the effects of vibration, heat and noise on human performance both individually and in combination. Vibration is of particular interest to those in the fields of military and aeronautical research.

Grether used ten male military personnel as subjects, with each experimental session lasting about 30 minutes. The experimental exposure values used are detailed in Table 5-1 below.

Table 5-1 Environmental Exposure Values used by Grether (1971)

Environmental Variable	Control/Ambient Condition	Maximum Condition
Heat	22.2°C (ET: 22°C)	48.9°C (ET: 31°C)
Noise (Broadband)	80 dB	105 dB
Vibration	0	5 Hz sinusoidal, 0.30 peak g. 35 min

Each subject was tested once daily, for five days. Every subject once completed a session in completely ambient conditions, once with each one of the variables at maximum, and once with all at maximum.
Grether follows a similar procedure to Pepler, where subjects are exposed to control conditions at the beginning and end of each session. Grether's use of a completely ambient session acts as a control for the arousal effects that may have been measured by Pepler. The order of testing was also blocked to control for learning.

When the results of sessions using only one variable were analysed, there was an increase in reaction time in comparison to the entirely neutral condition. Reaction time measured in the combined stress sessions were no more marked than the effects from single-stress conditions. Combined stress only caused the greatest performance decrement only a mental arithmetic test. Grether suggests that this could be due to a slight antagonistic reaction, but suggest that it is more likely to be due to chance factors. A follow up study was conducted to further examine these results in 1972, including physiological measures (Grether, Harris et al.). No significant differences were found on the arithmetic task. This task was error based, and so will also have missed any changes in speed of performance, causing the same problems as discussed in Chapter 3.

Hygge (1991) investigated the interaction of noise (38 dBA and 53 dBA, emitted by a commercial heat exchanger) and mild heat (19°C 17°C) on cognition and serial reaction time. Hygge assumes that noise increases arousal, and that mild heat decreases arousal, predicting an antagonistic interaction.

Hygge found no significant differences on a mental arithmetic task. Noise and temperature both had negative effects on a hidden figures task, and an antagonistic interaction together, where the slightly negative effect of one variable was counteracted by the other. Hygge explains these results using arousal theory, where mild heat is dearousing and noise is arousing.

No research has specifically conducted multivariate studies of mood, but Clausen and Carrick et al. conducted a comparative study of discomfort caused by indoor air pollution, thermal load and noise. In the range of 23°C to 19°C, a 1°C change in temperature was found to be equivalent to a change of 3.9 dBA in noise level. When tested individually both environmental conditions had the same effect on human comfort as 60 dBA of traffic noise. When the two stressors were combined, the equivalent noise level was 71 dBA. This increase is approximately the same as a doubling of loudness. These results can be used to propose a synergistic interaction between noise and heat on comfort.

5.4 Discussion and Conclusion

One of the interesting consequences of making a single-variable investigation, as outlined in the previous three chapters, is that the other environmental variables are always present. Despite this, a lighting researcher, for instance, will rarely control other thermal or background noise variables during the course of testing. As such, the results of the majority of single-variable studies are inherently unreliable, and the results of multivariate studies are of increased importance.

This chapter has examined the theories of the interaction of environmental variables, and discussed the available multivariate literature. The result of any combination of stressors should be able to be described as either;

1. Interactive:
    a. Synergetic
    b. Antagonistic
2. No interaction:
    a. Additive
    b. Subtractive
3. Parallel

These can be used to form hypotheses about interaction between variables, when the effects of individual variables are examined in the context of arousal theory.

The previous three chapters have allowed assumptions to be made about how temperature, lighting and noise are likely to act as environmental stressors. There is a consensus in the literature that noise increases arousal. There is evidence that increasing temperatures lower arousal. Whilst there is less evidence available for the effects of lighting level, it is suggested that it increases arousal.

Where there is research evidence to support the hypothesis that temperature and noise have an antagonistic reaction, there are none which consider the effect of lighting illuminance. It is proposed that illuminance will have the same general effects as noise.

Chapter 6: Methodology

6.1 Introduction

This chapter details the experimental design and methodology used in the research. As discussed in the literature review there are concerns regarding repeated administration of performance tests. This issue is explored further in a preliminary study, the results of which guide the final choice of experimental design.

The choice of performance task is critical. It must measure an aspect of performance relevant to a classroom context as well being suitably sensitive to changes in performance caused by the environmental variables. The performance task is discussed in view of these considerations. Choice of mood assessment is similarly complex, and a new method of measuring mood in this field of research is presented.

As this is a study of human behaviour, there are many extraneous variables which can influence performance, such as motivation and skill level. These issues are also discussed, and strategies are presented to control these outside effects. The chapter ends with a full methodology and description of experimentation.

6.2 Independent Variables

The independent variables under investigation are measures of the thermal environment, acoustic environment and lit environment. These three aspects of the classroom environment have been selected for investigation for a variety of reasons;

- The presence and control over these variables are engineering decisions, which must satisfy a variety of requirements made by Building Regulations, Building Bulletins, Workplace Regulations as well as users of the space. They are therefore of relevance to researchers interested in the Built Environment.

- They are the most commonly researched variables encountered in studies of environment and performance, but such knowledge has not been applied to the design and management of educational buildings.

The three independent variables can be measured in a variety of ways. The effects of background noise are often examined by type; Furnham and Strbac (2002), for example, compares the effects of music, office noise, and silence. Building Regulations and Bulletins are however concerned with the perceived loudness of noise, not its characteristics, and therefore sound pressure level is used to define noise requirements. As identified in the literature review, little research examines the relative effects of the same complex noise at various sound pressure levels, an omission addressed by this study.

Research concerned with the lit environment on non-physical performance is most often concerned with bulb type, and the resulting light spectra, than light intensity e.g. (Veitch, Gifford et al. 1991; Veitch 1997; Veitch and McColl 2001). This can perhaps be attributed to market forces, as manufacturers make contentious claims about the benefits of new technologies such as the 'daylight bulb'. Building Bulletins do suggest that classrooms in schools should be lit with lamps with "a Warm to Intermediate colour", given as less than 5300 K unless electric lighting supplements daylighting in which case Intermediate lamps of about 4000 K should be used (Building Bulletin 90:1999). Where lamp colour is only specified as a recommendation, statutory requirements are in place for provision of working plane lighting levels, being a minimum of 300 lux and 108 lux for England and Scotland respectively. In addition to these basic requirements Building Bulletins and design guides give more detailed and generous recommendations for working plane lighting level. As such the main descriptor of lighting in schools is the working plane lighting level, despite the lack of research addressing its effects on non-visual performance. This lack of knowledge is addressed by using working plane lighting level as a main independent variable in this study.

The thermal environment is characterised by the multitude of ways in which it can be measured. Whilst the thermal environment can be assessed by measurements of air temperature, humidity, etc, its effects can also be directly measured by measuring body temperature, sweat rates and so on. In addition to these simple scales, a variety of indices are available which attempt to integrate some or all of these variables into a single measurement. Research concerned with the thermal environment and non-physical task performance is complicated by this variety of measures, making comparison between studies problematic. Design guides and requirements for educational spaces use air temperature as a means of quantifying the thermal environment, presumably due to simplicity of measurement rather than suitability as an overall descriptor of the thermal environment. As such air temperature is the most relevant measure for inclusion in the study.

6.3 Choice of Performance Tasks

As performance research in its various forms has been conducted for decades, a large variety of tasks have been used to measure performance. This section discusses the range of considerations that must be made when choosing a performance task, such as the skill levels of the participants, task complexity and general relevance of the mental processes used.

Consideration must be given to the learned skills and innate capabilities of the participants taking part in the experiment. Hancock (1986) indicates that individuals who are skilled at the task they are performing, and are able to use relatively attention-free automatic processes will prove less vulnerable to stress effects of the environmental variables under consideration than their unskilled peers.

This phenomenon has previously been documented, with Mackworth (1950) in Bell and Provins (1962) linking competency to performance, in the course of researching the effects of thermal strain. Mackworth monitored the performance of wireless telegraphy operators receiving and recording nine Morse messages, over 16 minutes. Initially, as temperature increased so did error rate and with significant deterioration occurring at 87.5°F (31°C) (ET). All operators did not however deteriorate at the same point, and were divided into three categories based on skill level; "competent", "very good", and "exceptionally skilled". When examined in groups it appeared as if deterioration occurred at 87.5°F (31°C), 92°F (33°C) and 97°F (36°C) (ET) respectively; those with the highest mental load were most sensitive to deteriorations in performance caused by thermal stress. This demonstrates the importance of skill level to task performance, with the simplest control being to ensure that the task is new to all participants.

The idea of a higher mental load being more susceptible to the effects of environmental variables is readdressed by the issue of task complexity. Two separate studies conducted in 1958, by Pepler (1958) and Chiles (1958), using a paced complex mental task can be used to demonstrate the effects of task complexity on the sensitivity of performance measures.

Pepler (1958) found a significant deterioration at effective temperatures of 81°F (27°C) ET to 86°F (30°C) (ET). Chiles (1958) used a modified version of the test, but reduced the pace, effectively making the task easier. No performance deterioration was found even over a wider range of effective temperatures from 76°F (24°C) to 91°F (33°C). It would appear that as Pepler's subjects were being subjected to a more demanding mental load, they were more susceptible to the effects of the thermal variable.

It is worth noting that Pepler's subjects were located in Singapore and Chiles' in America, and so may have had different physiological and psychological responses to the thermal conditions imposed on them. Chiles himself concluded that the discrepancy between the experiments could be due to the different subjects used, or the longer session times of Pepler's study

Although these and other experiments show the need for tasks be sufficiently difficult, Griffiths and Boyce (1971) write of the need for tasks to be of less than maximum difficulty. Returning to the idea of an inverted-U hypothesis as discussed previously, using a task of more moderate difficulty allows a performance increment before it becomes disruptive and leads to a performance decrement.

These studies demonstrate that specialised tests of cognitive performance are required. A wide variety of such non-physical tasks have been used in similar studies over the decades, measuring a variety of aspects of human task performance. Older studies, interested in vigilance and reaction times often use testing apparatus, where respondents hit switches or buttons in response to lights or other signals (Grether, Harris et al. 1971; Grether, Harris et al.), and pursuit tracking tasks, where a pointer is used to follow a target (Pepler 1960; Grether, Harris et al. 1971; Grether, Harris et al. 1972).

More modernly, a range of tests have been used which are more relevant to a classroom context. These include tests of memory, problem-solving, reading comprehension, mental arithmetic and more. Such tasks engage a variety of mental processes.

Schweizer, in Schweizer and Moosbrugger (2004) and Schweizer, Moosbrugger et al.(2005) has repeatedly pointed out that successful completion of all such tasks relies heavily on being able to maintain attention for long periods of time at a high level. As such a review of suitable attention tests was completed, in order to identify the most appropriate format.

The memory-load search task, sometimes also described as the Search and Memory task, has been successfully used as an attentional measure in previous studies by Hygge and Knez (2001) and Bengtsson, Waye et al. (2004). Participants are required to search through a series of lines consisting of 59 capitalised letters for five target letters, which are presented at the beginning of each line. A low-memory load version of this test, as used by Bengtsson (2004) requires participants to only search for a single target letter. This test allows researchers to measure accuracy and speed by counting letters which have been missed and the number of letters which have been scanned.

Due to Hygge and Bengtsson's successes with the Search and Memory task (SAM), where both researchers found significant interactions between noise levels and speed of performance, the SAM was considered for inclusion in the test battery. A brief trial of the SAM, following the procedures described by both Hygge and Bengtsson, found that the majority of subjects made no errors and completed the test very quickly. As such, this form of the memory-load search task is considered to lack sufficient sensitivity for this context.

The underlying principles of the test are still valid however, particularly the measures of both speed and error rates, which have been identified in the literature review as being required for an all round measure of performance. A review of literature concerned with psychometric testing identified a test based on very similar principles, the d2 Test of Attention, which yields similar types of scores. The d2 test of attention has been successfully used by researchers in other fields to measure attention levels i.e. Trimmel and Poelzl. A trial of the test showed that it was easily understood as well as sufficiently difficult, and the d2 test was therefore chosen as the attentional measure. Additionally, the d2 test of attention has a minimised relationship with intelligence, making it particularly useful for this type of research (Brickenkamp and Zillmer)

6.3.1 d2 Test of Attention

The d2 test of attention was first published by Rolf Brickenkamp and Eric Zillmer in 1962, and has since undergone eight revisions. The version of the test used in this study is the most recent, and was published in 2003 (Brickenkamp and Zillmer 1998). The administration and scoring of the test is fully described in the d2 test of attention manual which accompanies the test.

Description of Test

The d2 test is a standardised version of a pen and paper cancellation test. These tests measure processing speed, rule compliance and quality of performance which requires the respondent to discriminate between similar visual stimuli.

The d2 test consists of a sheet of A4 paper used in a landscape orientation, with the test on one side and a sample practise line on the other. The test itself consists of 14 lines comprising of 47 characters each. The characters are all either a "d" or a "p", accompanied by one, two, three or four dashes each. The dashes are arranged above or below the character, and appear individually or as part of a pair. Figure 6-1 shows part of a typical line. A full copy of the test can be found in Appendix 6 A.

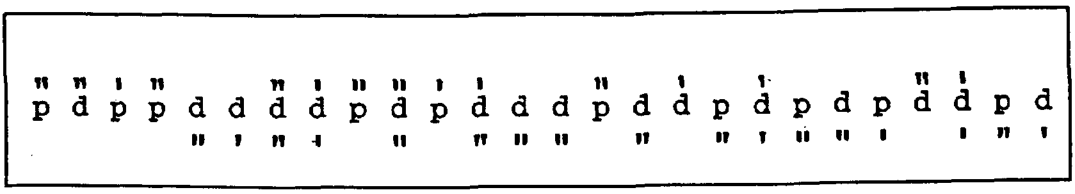


Figure 6-1 Part of a typical line from the d2 Test of Attention

The subject is required to search each line from left to right, and mark each "d" that is shown with two dashes, hence the name of the test. Each "d2" is referred to as a relevant item, and all others are irrelevant items. The ratio of relevant to irrelevant characters is 1:1.2. The respondent is given 20 seconds to complete as much of the line as they can, before having to move to the next line.

The most significant difference between the d2 test and the SAM is that subjects are searching for the same character throughout the d2 test, rather than searching for multiple characters, or changing characters for each line. As such the d2 test requires less of a memory load than either version of the SAM, and is therefore a more accurate measure of concentration.

Scoring

The test is accompanied by two scoring keys, translucent pieces of acetate printed so that when placed over a completed test, either relevant or irrelevant items are obscured. This ensures that the marking process is subject to a minimum of errors. A number of quantitative measurements are used to calculate qualitative scores for the d2 test.

Quantitative Scores

Total Number of Items Processed (TN)

The most basic measure of speed is the number of items processed, regardless of correctness. Scores are limited by the number of characters in the test. With 47 characters in each line, the number of items processed, relevant or irrelevant (n), for each line, is limited to;

$$0 \leq n \leq 47 \qquad (6\text{-}1)$$

The number of items processed for all 14 lines of the test, relevant or irrelevant (TN) is therefore;

$$TN = \sum_{a=1}^{14} n_a \qquad (6\text{-}2)$$

Where n_a is the number of items processed, relevant and irrelevant, for each line. Thus;

$$0 \leq TN \leq 655 \qquad (6\text{-}3)$$

A higher TN indicates a faster processing speed.

Correct relevant items (NC)

The number of correctly identified relevant items for each line (nc), or the whole test (NC) are raw scores forming the basis for other qualitative measures.

Errors (E)

Two types of errors can be made, errors of omission and errors of commission. Errors of omission occur when relevant items have not been marked by the participant, and errors of commission occur where irrelevant items are erroneously marked. Errors of the latter are less common than those of the former.

The total number of errors for the whole test (E) is;

$$E = \sum_{a=1}^{14} \left(e_{O_a} + e_{C_a} \right) \qquad (6\text{-}4)$$

Where e_{O_a} is the number of errors of omission for each line of the test and e_{C_a} is the number of errors of commission for each line of the test.

Qualitative Scores

Percentage of Errors (E%)

One method of combining speed and accuracy calculates the percent ratio of errors to items processed (E_{PC})

$$E_{PC} = \frac{100E}{TN} \qquad (6\text{-}5)$$

Smaller E_{PC} scores indicate higher accuracies of work.

TN-E

The TN-E score represents the quantity of work completed after correction for errors. It is arrived at by deducting the total number of errors (E) from the total number of items scanned (TN).

This method of measuring the relationship of speed and accuracy to performance provides a measurement of attention but can be liable to overestimation, as described below.

Concentration Performance (CP)

Concentration Performance is another qualitative measure of speed and accuracy of performance. Concentration Performance for each line of the test (cp) is arrived at by deducting commission errors (e_{C_a}) from the number of correctly crossed out relevant items (nc). Concentration Performance for the whole test (CP), can therefore be written as;

$$CP = \sum_{a=1}^{14}\left(nc_a - e_{C_a}\right) \tag{6-6}$$

CP cannot be distorted by respondents crossing out all the characters whether relevant or not, or by respondents skipping sections of the line.

TN-E can often be subject to this distortion by giving more weight to the quantitative and less to the qualitative aspects of performance. Where both quantitative and error scores are extremely high TN-E will give an over estimation of performance where CP will not.

Consistency

Fluctuation Rate (FR)

Fluctuation Rate (FR) is the difference between the line with the greatest number of items processed (n_{max}) and the line with the least number of items processed (n_{min}).

$$FR = n_{max} - n_{min} \tag{6-7}$$

A high FR score indicates an inconsistent work speed.

6.3.2 Mood assessment

A variety of methods of mood assessment are available to researchers. Due to claims by 'daylight bulb' manufacturers that their products can enhance mood, most research investigating the effects of indoor environmental variables on mood are interested in the lit environment, and comparatively relatively little literature examines the effects of noise and temperature. As such most of the literature used to demonstrate the choice of mood assessment is from lighting research.

One of the most frequently encountered methods of mood assessment is the Positive and Negative Affect Scale, or PANAS, used extensively by Knez (Knez 1995; Knez and Enmarker 1998; Knez and Kers 2000; Knez 2001), and also Boyce, Eklund et al. (2000) in studies of lighting and performance.

The terms Positive and Negative Affect (PA and NA) sound like opposites, but are described as distinctive dimensions by Watson (1998), who developed and validated the PANAS;

"Positive Affect reflects the extent to which a person feels enthusiastic, active and alert...Negative Affect is a general dimension of subjective distress and unpleasurable engagement that subsumes a variety of aversive mood states including anger, contempt, disgust..." (Watson and Clark 1988)

The PANAS consists of ten mood descriptors which are relatively pure markers of either PA or NA. Subjects are asked to evaluate their current state of affect using a five point scale ranging from "little or not at all" to "very much". Categorical responses of this nature are known as Likert scales, named after Rensis Likert, who published a document in 1932 detailing their design and use (Likert 1932). This type of scale is generally considered to be quick to use and administer.

Use of the PANAS in lighting studies has resulted in the identification of statistically significant interactions by Knez, who is primarily interested in the effects of the colour of fluorescent light on mood and performance. Results have been mixed and have not revealed a consistent pattern of mood change induced by lighting. In 1995, Knez conducted a two part study, where colour temperature showed a significant interaction with NA, and none with PA in the first part, and colour temperature and illuminance significantly interacted with PA, but not NA in the second part (Knez 1995). In 1998, correlated colour temperature correlated with PA and NA (Knez and Enmarker 1998). In 2000, colour temperature was found to affect NA but not PA (Knez and Kers 2000). In 2001 no significant results were obtained using the PANAS (Knez 2001). Whilst Knez's work certainly shows that the colour of light affects mood, it also indicates that the PANAS may not be a sufficiently sensitive measure, due to the assumption of only two dominant dimensions of mood.

The same principles as the PANAS are used in the Activation-Deactivation Adjective Check List (AD-ACL), and the Mood Adjective Checklist (MACL). These assessments also use Likert Scales to examine predetermined facets of mood. Gawron (1984) used the AD-ACL to show negative mood in quiet, and Nelson, Nilsson et al. (1984) used to the MACL to show poorer mood in cool-bright and warm-dim conditions.

The same principle of using a point-scale to agree with adjectives is seen in the Sjoberg mood questionnaire, used by Bengtsson, Waye et al. (2004) and Waye, Ryelander et al. (1997). 71 adjectives describe different feelings, and have four possible response alternatives, ranging from "I agree completely" to "I do not agree" categorised into six mood dimensions (social orientation, pleasantness, activation, extraversion, calmness and control). Only one dimension has been found to be significantly affected by an environmental variable; social orientation to low frequency noise. This does however demonstrate the benefits of dividing mood into a number of facets.

Others have based their mood assessment on the Mehrabian and Russell pleasure-arousal scale, which assumes three emotional dimensions: pleasure, arousal and dominance (Mehrabian and Russell 1974). Mood assessments are made on bipolar scales (i.e. comfortable - uncomfortable), ranging from "not at all" to "very much".

Boray, Gifford et al. (1989), using this method, found no association between various colours of fluorescent light (warm white, cool white, 'full spectrum') and mood, where Knez's results suggest one should be found. The most likely reason for Boray's result is that only three bipolar scales were used to assess mood, one for each emotional dimension, resulting in a severe loss of measurement sensitivity.

Veitch, Gifford et al. (1991) use an 18-item five-point version of the scale to test the differences between full spectrum fluorescent lamps and cool white fluorescent lamps. Like Boray, no effect on mood was found, but as the mood assessment was more thorough Veitch's result is more reliable than Boray's. Veitch's finding are reinforced by a repeat experiment in 1997, where again no effect was found on mood.

Without criticising the reliability or validity of Veitch and Boray's findings, it would not be prudent to use a method of mood assessment which had not been shown to consistently measure changes.

Another method of mood assessment is to use a mood checklist, where subjects select words which they feel best describe their state from a list. There are various forms of this assessment, based on Zuckerman's Multiple Affect Adjective Checklist (MAACL) of 1965 (Zuckerman and Lubin 1965). This method of assessment whilst useful for clinical assessments, does not lend itself well to statistical analysis.

The rating methods for all of the above methods of mood assessment, with the exception of the MACL, are the same in that they require categorical responses to be made. An alternative to these Likert-type scales is the Visual Analogue Scale, or VAS, a scale which measures a variable on a continuum. This type of scoring system does not force the subject to fit their emotions into a discontinuous Likert-like grading scale, as argued by (Folstein and Luria 1973).

The VAS was first developed in 1921 by Hayes as a method for superiors to rate subordinate workers without the use of direct quantitative terms whilst allowing fine discrimination (Hayes and Patterson 1921). Zealley and Aitken first used the VAS for self-measured mood assessment in 1969 (Ahearn 1997), where a single scale was used to rate patients between 'normal' and 'most depressed' (Zealley and Aitken 1969).

Use of the VAS as a mood assessment has been by clinicians, in either drug trials or psychiatry. As such, using only a single scale was a useful way to make a quick assessment. Folstein and Luria (1973) argued that a single overall mood scale was in fact more useful than multiple scales, as they do not suggest any particular qualities of mood to the subject. Despite such concerns, the VAS has been used to compose mood assessments using multiple scales.

They are quick to administer and the method is easily explained to users. Modern technologies are stimulating research interest in the VAS. As the VAS can now be administered by a hand held device, rather than the traditional paper and pencil test, researchers are interested in assessing whether this change in medium can affect VAS scores i.e.Tseng, Macleod et al. (1997) and Kreindler, Levitt et al. (2003).

The use of the VAS was reviewed by Freyd in 1923, who made several suggestions about the VAS that are still adhered to today (Ahearn 1997). The VAS should be no more than five inches in length, and the standard VAS length today is 100mm. The extremes of the variable being measured should be defined in simple terms, known as 'anchor words' and placed at each end of the line. Favourable extremes of the scale should be alternated, to eliminate motor tendencies to check one margin of the page (Freyd 1923). A typical general mood VAS as described by Luria (1975) is shown Figure 6-2.

Figure 6-2 Typical VAS or Mood Slip

Using a method of mood assessment utilising a VAS has the advantage of extreme sensitivity, a requirement for measuring the often small effects of environmental variables. One such scale is the Bond Lader mood assessment (Bond and Lader 1974), which has been successfully used to measure drug effects (Kennedy, Scholey et al. 2002).

The Bond Lader mood assessment is a series of sixteen VAS's, with bipolar adjectives such as 'calm-excited'. The authors administered the test to 500 subjects, and subjected the results to a factorial analysis to extract three factors, entitled Alertness, Contentedness and Calmness. The Bond Lader test can be analysed on the basis of these three factors, but has the flexibility to be retested by factorial analysis to ascertain the number of factors which should be extracted from that particular data set. This avoids the problems of mood assessments which presuppose a number of emotional dimensions. As such it is an opportunity to identify which dimensions of mood are affected by the environment as examined in this thesis. The administration and scoring of the Bond Lader mood assessment are detailed as follows.

Bond Lader Mood Assessment

The Bond Lader mood assessment consists of 16 ten cm VAS's, each with bipolar adjectives at either end of the scale as shown in Figure 6-3 (not to scale). Subjects record their position on each spectrum by means of a vertical line. Scoring the test is accomplished by measuring the distance along the line, and recording the distance in millimetres (mm) to generate a score for each variable between zero and 100.

The 16 measurements will load onto either three or four factors, as shown by Bond, demonstrating that an abbreviated form of this assessment is possible. Bond recommends retaining all 16 points, to avoid a loss of reliability. The scale is so quick to administer and score that no benefit would be gained from reducing the size of the assessment.

Using the principles of the VAS and Bond Lader scale, an additional scale relating to perceptions of the test environment was constructed (Figure 6-4, not to scale). The Environmental VAS allows the participants to record their assessment of temperature, lighting and noise as well as an overall impression of the comfort of the environment. This can be used as a check to ensure that subjects respond to the environments in the way that is expected (i.e. colder temperatures are rated as cooler environments).

Scores from the Environmental VAS also can be compared to investigate differences in response to the test environments. This part of the questionnaire can also be used to examine the relative importance of temperature, lighting and noise to overall comfort.

For completeness two additional scales were used to assess hunger and an overall self assessment of mood (Figure 6-5, not to scale). The assessment of overall mood will be in interesting cross check with the results of the Bond Lader mood assessment. An assessment of hunger is also included, to control for any possible effects of hunger on both mood and concentration.

Alert	————————	Drowsy
Calm	————————	Excited
Strong	————————	Feeble
Muzzy	————————	Clear Headed
Well Coordinated	————————	Clumsy
Lethargic	————————	Energetic
Contented	————————	Discontented
Troubled	————————	Tranquil
Mentally Slow	————————	Quick Witted
Tense	————————	Relaxed
Attentive	————————	Dreamy
Incompetent	————————	Proficient
Happy	————————	Sad
Antagonist	————————	Amicable
Interested	————————	Bored
Withdrawn	————————	Gregarious

Figure 6-3 Bond Lader mood assessment

Too Hot	————————	Too Cold
Too Bright	————————	Too Dim
Too Noisy	————————	Too Quiet

How comfortable do you find the room that you are in?

Best Ever	————————	Worst Ever

Figure 6-4 Environmental VAS

Hungry ———————————————— Full

Overall, how would you rate your mood at the moment?

Best Ever ———————————————— Worst Ever

Figure 6-5 Additional VAS

Combining the Bond Lader scales, environmental VAS and additional scales has resulted in a comprehensive 22 point test, used as presented in Appendix 6B. The scalar nature of the VAS ensures a higher degree of accuracy than other forms of mood assessment, which require a categorical response. The responses from this part of the test battery can be used for a variety of analytical purposes, such as investigating the relationships between environment and mood, and as a basis for investigation of the interactions of mood and performance.

6.3.3 Word Fluency

While the d2 test is a reliable measure of concentration performance, it does not replicate any type of task which would be performed in a classroom setting. A review of performance tasks was conducted in order to highlight tests that could be used to replicate classroom or examination activities.

Tests of mental arithmetic have frequently been used in environmental performance literature, i.e. Belojevic, Slepcevic et al. (2001), Boray, Gifford et al. (1989), Furnham and Strbac (2002), Gawron (1984), Givoni and Rim (1964), Grether, Harris et al. (1971); Grether, Harris et al. (1972), Vasmatzidis, Schlegel et al. 2(002), Veitch, Gifford et al. (1991; Veitch (1996), but this type of task is similarly not encountered routinely in universities.

Reviewing Hygge's studies of noise and memory (Hygge, Boman et al. 2003) and heat, noise and performance (Hygge 1991), highlighted the use of a word fluency test. Word fluency tests originate in the field of clinical neuropsychology, where they are considered to be highly sensitive measures of cerebral dysfunction. Studies have shown increased 'left brain' activity associated with the task (Ruff 1997).

Subjects have to think of a number of words that meet a predefined condition (i.e. begin with the letter 'A') in a time-pressured situation. The scoring method uses both the volume of words generated by an individual and the relative uniqueness of the words across all tests. This test can be paralleled with essay writing tasks in the classroom and examination hall, as both rely on the quickness and creativeness of word recall.

An informal trial of this test for this study led more than one participant to comment that they had experienced a "mind blank" and that there was a "word on the tip of my tongue I just couldn't get out". These were particularly interesting comments in the context of this study – most lecturers and teachers will be able to recall anecdotes of students reporting similar experiences in exam situations.

When the word fluency test was used by Hygge in 1991, to test interactions of noise (38 dBA and 53 dBA) and mild heat (19°C and 27°C) no significant effect was found. In 2003 however, a significant effect of road traffic noise was found on the third part of the word fluency test. As this study uses traffic noise as a significant component of background noise, it also provides a useful opportunity to expand on Knez's 2003 study by testing the effects of road traffic noise at a range of sound pressure levels, as well as to examine any effects of lighting.

Description of Test

Respondents are given two minutes to write down as many words as they can that begin with a predefined consonant, and conform to a predefined condition. Three tests are administered in increasing amounts of difficulty, as illustrated in Figure 6-6.

Please write down as many words as you can;

- **that begin with the letter A**
- **that have five letters and begin with the letter M**
- **that are professions beginning with the letter B**

Figure 6-6 Three Word Fluency Tests

Scoring

The scoring system as described in Hygge (1991) scores the number of words in addition to a sum quality-weighted score for each word. The quality score for each word is defined by the formula;

$$x = \frac{\log\left(\frac{N}{n}\right)}{\log(2)} \qquad (6\text{-}8)$$

where N is the number of subjects in the experiment and n is the number of persons which have reported the word in question. This results in a higher score being generated for rarer words.

6.4 Experimental design

Having defined the environmental variables under investigation, and chosen the d2 test as a measure of concentration, an experimental design can be constructed. As previously discussed, requiring subjects to complete the same task multiple times as part of a within subjects experimental design can be problematic. A range of unwanted effects can arise from learning, boredom or fatigue, as well as the possibility of subjects changing strategies between tests. To address these concerns a preliminary investigation of the effects of repeated administration of the d2 test of attention was conducted.

6.4.1 Preliminary Investigation

The majority of similar research in the field uses within-subject experimental designs, where repeated measurements are made from the same subjects as they perform the same tasks under different conditions. This has raised concerns about the effects of repeated administration of the d2 test of attention. A preliminary study was conducted in order to assess the suitability of this type of method for this research.

Description of Preliminary Study

The study was conducted in the same environmental chamber with the same equipment described in later sections of this chapter. Background noise was composed of noises that would typically be found in a study or examination environment, consisting of coughing, scraping chairs, doors closing, rustling paper and stationery rattling. Human speech was deliberately excluded, due its complex effects on concentration and performance as described in section 2.2.2.

Tests were conducted at approximately the same time each day commencing at 10AM, and sessions lasted approximately three and a half hours each. Participants were not told of the purpose of the tests or allowed to see the chamber being adjusted between tests. Testing sessions were held using one person at a time,

A total of 16 subjects completed the study. Participants were randomly allocated to one of three groups. Each group was tested using temperature, lighting, or background noise as the independent variable. The range for these variables (Table 6-1) was based around typical environmental variables which would be found in a lecture room.

Table 6-1 Levels of Dependant Variables

	Temperature (^oC)	Lighting (lux)	Background Noise (dBA)
Low	12	200	20
Medium (control)	18	400	40
High	24	600	60

Each participant undertook the d2 test of attention five times, and was given a half hour break between tests. Every participant completed the first, second and last test under the same medium conditions of 18°C, 400 lux and 40 dBA to act as a control. Tests three and four were conducted in the same manner but with the group's independent variable set at either high or low levels. Half of each group completed the third test with the variable set to high, and the fourth at low, and the other half of the group vice versa.

Scores were tested for normality using the Shapiro-Wilk test for normality, and were not found to be normally distributed. As such the non-parametric Wilcoxon signed ranks test was used to make paired comparisons between the scores on each test. This test yields a z statistic, indicating the size and direction of the difference between scores, and the level of statistical significance (p) (Hinton, Brownlow et al. 2004).

Speed of performance (TN) and overall performance (CP) were found to be significantly different between the first and last testing sessions ($z=-3.157$, $p=0.00$ and $z=-3.516$, $p=0.000$ respectively), and between second and fifth tests ($z=-3.336$, $p=0.001$ and $z=-3.362$, $p=0.01$ respectively), where speed of performance and overall performance improves with retesting. Error scores E1, E2 and E showed no significant differences. This is in direct contrast to Pepler's result, where a progressive decrease in performance was found. This implies that a learning or motivation effect is being measured, as opposed to the "fatigue or time effect" identified by Pepler.

Pepler's convention of discarding the results of the first testing session, assuming that initial results are not representative of normal performance, was followed. By assuming that the rate of learning is linear, scores in the second and last sessions can then be interpolated to hypothesise performance in the third and fourth tests under controlled conditions, as shown in Table 6-2 for the lighting group.

Table 6-2 Interpolation of TN results for lighting group

	Test Session			
	2 (TN)	**3 (Predicted TN)**	**4 (Predicted TN)**	**5 (TN)**
Person A	632	631.33	630.67	630
Person B	453	468.00	483.00	498
Person C	455	461.00	467.00	473
Person D	517	533.00	549.00	565
Person E	477	495.67	514.33	533
Person F	466	469.33	472.67	476

Figure 6-7 illustrates results from two individuals from the lighting group showing interpolated projected performance, and actual performance in the middle tests. Both individuals undertook the third test in bright conditions, and the fourth test in dim conditions.

Person A, unlike most of the other subjects showed a very slight performance decrement between the second and last performance sessions, although their scores were consistently higher in comparison to the other subjects. In both the dim and bright conditions Person A performed faster than hypothesised, this being more marked in the dim condition.

Person B shows a more representative pattern of performance, where overall speed of performance increased between second and last testing sessions. TN for the third test, in the bright condition, was very close to the predicted result, being one point less than hypothesised. Performance in the fourth test was poorer than predicted.

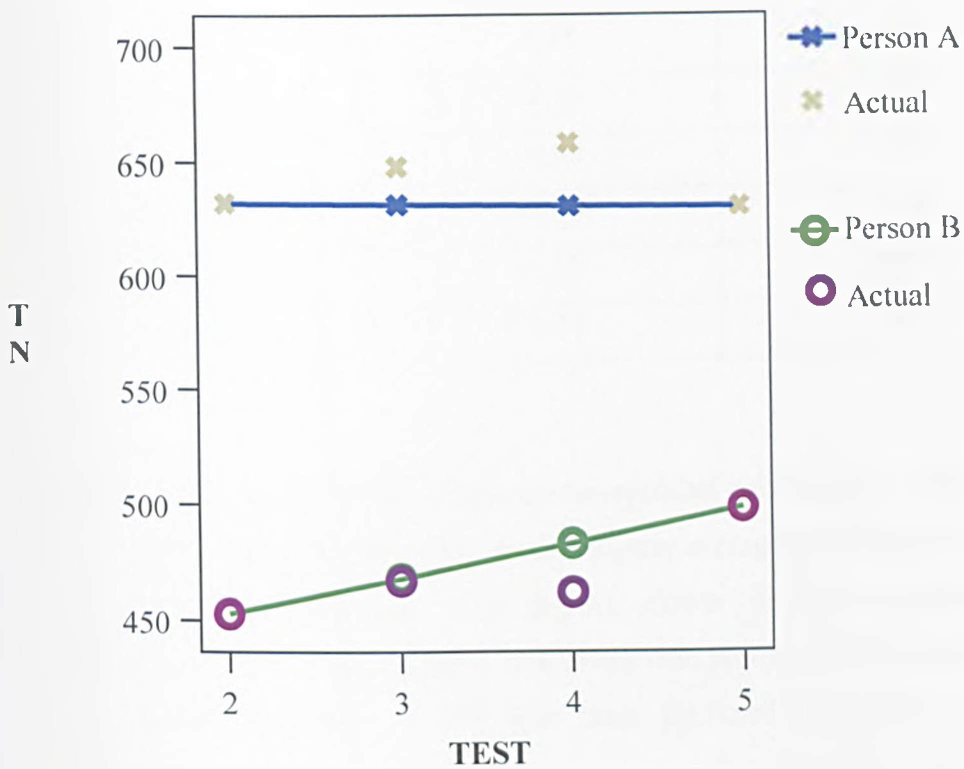


Figure 6-7 Actual and predicted TN for two subjects in the lighting group

This method can be extended to show the percentage difference between expected performance and actual. Table 6-3 shows the differences between interpolated performance and measured speed of performance (TN) for the individuals assigned to the Lighting group. As the order of presenting the lighting conditions is balanced between the third and fourth tests, this can be presented as the differences measured between conditions.

It can be seen that most individuals performed more slowly than expected in the dim condition to a greater extent than in the bright condition. When averaged the differences are small; speed of performance was 1.37% slower in dim conditions than predicted with a Standard Deviation (SD) of 5.65, and 0.02% faster than predicted in bright conditions (SD=3.18).

Table 6-3 TN for Lighting group

	Difference in Dim Condition (TN %)	Difference in Bright Condition (TN %)
Person A	4.33	2.64
Person B	-4.35	-0.21
Person C	-9.54	-5.57
Person D	-3.10	3.38
Person E	5.57	0.67
Person F	-1.14	-0.78

Table 6-4 illustrates differences between interpolated performance and measured speed of performance for the Noise group. Again, averaged differences are small, where speed of performance was slightly slower in both conditions than hypothesised; TN was on average 0.71% lower than predicted (SD=2.09) in noisy conditions, and averaged 0.39% less than predicted (SD=5.72) for quiet conditions.

Table 6-4 TN for Noise group

	Difference in Noisy Condition (TN %)	Difference in Quiet Condition (TN %)
Person G	-2.08	9.91
Person H	2.50	-4.32
Person I	-2.97	-5.45
Person J	-1.30	1.39
Person K	1.14	-4.03
Person L	-1.54	0.18

Table 6-5 illustrates differences between interpolated performance and measured speed of performance (TN) for the Temperature group. On average, subjects performed faster then predicted (2.59 %, SD=3.95) in cool conditions, and slower in warm conditions (-0.88 %, SD=0.87).

Table 6-5 TN for Temperature group

	Difference in Cool Condition (TN %)	Difference in Warm Condition (TN %)
Person M	2.59	0.42
Person N	7.89	-1.48
Person O	1.44	-1.22
Person P	-1.57	-1.25

Individual results for overall performance as measured by CP, (detailed in Appendix 6 A) show a similar pattern to TN, as C P is dependant on TN. Table 6-6 shows the average differences between interpolated and actual overall performance for all groups.

Table 6-6 Difference between interpolated and actual CP

	Dim	Bright	Noisy	Quiet	Cool	Warm
Difference (CP %)	2.05	0.23	**0.75**	-2.24	**4.17**	**0.18**
Standard Deviation	8.88	3.47	5.85	7.95	5.48	1.20

This preliminary study is of a small sample size, and as such standard deviations would be expected to be large. This goes some way to explaining some anomalies, such as overall performance measured on noisy conditions being better than interpolated, where speed of performance was slower.

As is evident, this method of experimental method and analysis is based an assumption that performance over multiple test improves or deteriorates in a linear manner. Examining individual test results does not necessarily support this assumption. Half of the subjects gave their best performance in the third or fourth test, rather than the last. Almost a quarter of subjects gave their worst performance in the second and third tests, rather than the first. The results of Person A (Figure 6-8) are a good example of a learning curve, where performance improves, peaks and then falls, perhaps as a result of loss of motivation, tiredness or boredom. Person C shows a different pattern of performance, where a sharp decrease in performance was measured after an initial period of learning or motivation, which later recovers.

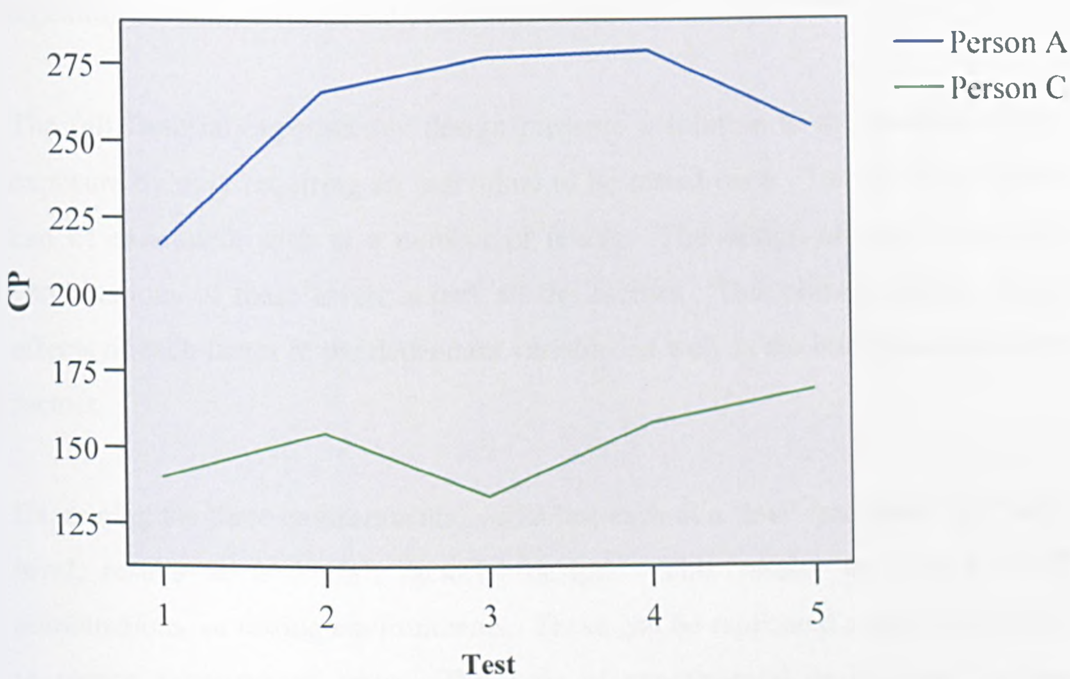


Figure 6-8 Two examples of performance over multiple tests

Taking Person A as an example, the increases in performance in tests 3 and 4 may as well be due to a peak of effort as due to any effects of the environment. Similarly, the performance decrement shown by Person C in test 4 could equally be attributed to a loss of motivation and concentration due to fatigue as to the dim conditions. It is feasible that dim condition could exacerbate feelings of fatigue, or motivation but using this type of design the effects are indistinguishable from each other.

In addition, this type of design necessitates the test to be first administered in a control condition, where the subject becomes accustomed to completing the test in a controlled environment. It is reasonable to hypothesise that performance will be affected more by subsequent changes to the environment, than the absolute levels of the environmental variables themselves.

This research is concerned with immediate effects, rather than responses to changes in the environment, another argument for using a methodology which requires the individual to only be tested once. This increases the repeatability of the experiments, as it removes the numerous psychological effects created by repeating the same experiment on an individual.

The full factorial experimental design presents a solution to the problems of re-exposure by only requiring an individual to be tested once. Two or more factors can be examined, each at a number of levels. The design utilises all possible combinations of these levels across all the factors. This allows analysis of the effects of each factor in the dependant variable, as well as the interactions between factors.

Examining the three environmental variables, each at a 'low' 'medium' and 'high' level, results in a 3^3 full factorial design. This results in a total of 27 combinations, or testing environments. These can be replicated a number of times to reduce experimental error. This type of experimental design has not been commonly utilised by researchers investigating the environmental and performance.

In instances where the full factorial design has been used, e.g. Wigö and Knez, subjects complete the test twice, and differences in performance are examined. Wigö chooses this type of design specifically to "focus on the exposure effects over time". As mentioned earlier, this study is intended to examine the absolute effects of the three environmental variables, and as such subjects will take the test only once, and be compared to each other.

6.5 Experimental Challenges

As just discussed, a number of potentially confounding variables are encountered in studies of this nature. These centre on individual ability and motivation of the human subjects, and can be addressed through careful choice of incentive and task complexity. These issues are discussed using as examples studies which have achieved inconclusive results due to such issues.

6.5.1 Concealing the Purpose of the Research

One of the first and incidentally one of the most famous (Bonnes and Secchiaroli; Cole; Veitch and McColl) series of studies concerned with work performance and an environmental variable are the 'Hawthorne Studies', conducted by Elton Mayo at the Hawthorne plant of Western Electric Company between 1927 and 1932 (Cole 2000). The Hawthorne Studies were originally intended to investigate the effects of workplace lighting on performance, using factory assembly employees as subjects, with those involved in the study moved to a separate part of the plant for observation. A correlation between lighting levels and productivity was hypothesised (Bonnes and Secchiaroli 1995) but it was instead observed that both the control group and the group subjected to varying lighting levels continually improved their productivity regardless of illumination (Cole; Veitch and McColl; Hansson and Wigblad).

These studies have not attained their classic status due to findings connecting lighting to productivity, as originally addressed in the research aims, but due to the myriad of hypotheses that have been offered to explain the continual increase in productivity, holding applications in the field of management science as well as environmental sciences.

Mayo himself argued the productivity increase was due to an increase in motivation caused by the personal attention paid to subjects in the study, as well as the novelty of the program (Leonard and Masatu). Subsequent researchers have questioned this conclusion, attributing factors such as an underlying threat of being removed from the program to the improving performance (Hansson and Wigblad), as well as making more general challenges to the methodology (Adair; Cole; Leonard and Masatu) and experimental rigour (Diaper) of the studies, and criticising the empirical evidence itself (Fostervold, Buckmann et al.).

Regardless of the ongoing debate over the real cause of the unexpected productivity increase, the Hawthorne Studies are used in management science texts to demonstrate the importance of human relations and management style in the workplace reasoning that the changed management style was responsible for the productivity increase (Cole 2000). More relevant to this piece of research, they can also be used to exemplify the types of difficulties inherent in studies investigating human performance, demonstrating that human participants can be a confounding factor in field experiments.

The change in productivity is also often attributed to the workers' awareness of being monitored as part of an experiment, altering their attitude towards their daily work. Attitude, or motivation, is supposed to have affected productivity more than the lighting conditions originally under examination. Such situations where an individual's behaviour is altered by their awareness of being under observation are frequently referred to as a 'Hawthorne Effect' (Adair; Fostervold, Buckmann et al.). Definitions of the Hawthorne Effect are ambiguous, and the term is also used to mean a positive and temporary change in behaviour (Diaper; Hansson and Wigblad; Leonard and Masatu).

Despite the arguments and lack of clarity surrounding the Hawthorn Studies, and the cause of the original Hawthorne Effect, it remains a concern to researchers involved in field studies. Control groups for 'Hawthorne' variables have been used, where groups complete placebo activities (Adair), and the variables and purpose of the experiment under investigation are withheld from the subject (Veitch and McColl). This is problematic when studies involve environmental variables, as concealing unusual or extreme conditions (i.e. cold temperature, bright light) from participants can be impossible. Studies in laboratory conditions are not so susceptible to the Hawthorne Effect due to the contextual differences, but it is still customary to withhold the purpose of the research from subjects.

6.5.2 Incentive, Motivation and Effort

The measurement of performance is further complicated by the difficulty of measuring effort. Measuring individual effort on a task is particularly problematic when considering non-physical tasks. When assessing a task of physical exertion, for example, it is possible to make an assessment of effort by monitoring physiological changes such as body temperature or sweat evaporation. The type of effort expended on a non-physical task is less easily observed and measured, and it is possible for subjects to perform below their capacity without detection, as Bell and Provins (1962) explain;

"even under carefully controlled conditions with highly motivated subjects, changes in test performance are only partially a reflection of changes in capacity. It is probable that reduced performance under these conditions does indicate a reduced capacity. A failure to observe decreased performance would not, however, be a conclusive demonstration that capacity remains the same".

There is therefore a need to ensure that participants in an experiment are expending a suitable level of effort during the task, with motivations exceeding *"the usual, rather complex, social ones involved in fitting in with the instructions of an experimenter"* (Broadbent 1971), where participants would like to appear cooperative, but have no personal involvement or motivation.

The problem of controlling a variable as intangible as effort, is often addressed through the use of incentive to produce motivation. Incentives have taken a variety of forms in studies investigating non-physical tasks, but most common are periodic feedback on test scores throughout testing or a set payment or reward for participation.

Different motivations will provide different levels of effort. Encouraging participants to continually improve their performance with feedback could result in a continually increasing level of effort being expended throughout the task. A set payment could result in a constant level of effort throughout the task, or even a decreasing level of effort as participants lose interest in the task.

An intermediate approach has been chosen for this experiment, where subjects are asked to volunteer their time for free. As subjects will be drawn from the student population, often from the same course, the opportunity will be given to those who participate to privately see their scores in comparison to the anonymised remainder. This is to create a semi-competitive atmosphere between participants to encourage motivation.

6.6 Method

As discussed previously in this chapter a full factorial design is most appropriate for use. Three variables are under consideration, working plane lighting level, measured in lux, noise measured by sound pressure level, and climate as defined by air temperature. As Hygge and Knez (2001) have highlighted previously, a minimum of three levels are ideally required to detect inflection points or performance peaks. This results in a 3x3 experimental design, as shown below.

Table 6-7 Experimental design

	Temperature (°C)	**Sound Pressure (dBA)**	**Light (lux)**
Low	5	40	200
Medium	17.5	60	600
High	30	80	1000

There are therefore a total of 27 different experimental conditions, each experienced by 6 individuals. Due to difficulties in finding volunteers testing ceased after 133 of the 166 tests had been completed. This has minimal implications for the statistical reliability of the results, as more than four individuals experienced each experimental condition, and the overall sample size is still large.

University students, only occupying lecture rooms for one or two hours at a time, are given less time to acclimatise to the thermal environment, as detailed in Chapter Three. As such, it was important to limit the length of the testing session. It has also been noted in the literature review that performance may be more severely affected by environmental conditions over short periods of time, suggesting that university students may be more susceptible to the effects of the environment than other groups i.e. office workers or school children, who stay in the same environment all day. The testing chamber was capable of maintaining a constant temperature for around 40 minutes, at which point noisy climate control equipment would be required. As such the sessions were designed to last for 30 minutes, comprising half of a typical one hour lecture.

6.6.1 Environmental Chamber

Testing was carried out in a windowless chamber, sized 3 x 6 x 3m. Figure 6-9 (not to scale) shows the layout of the room. Standard desks and chairs as would typically be found in classrooms were placed in the room.

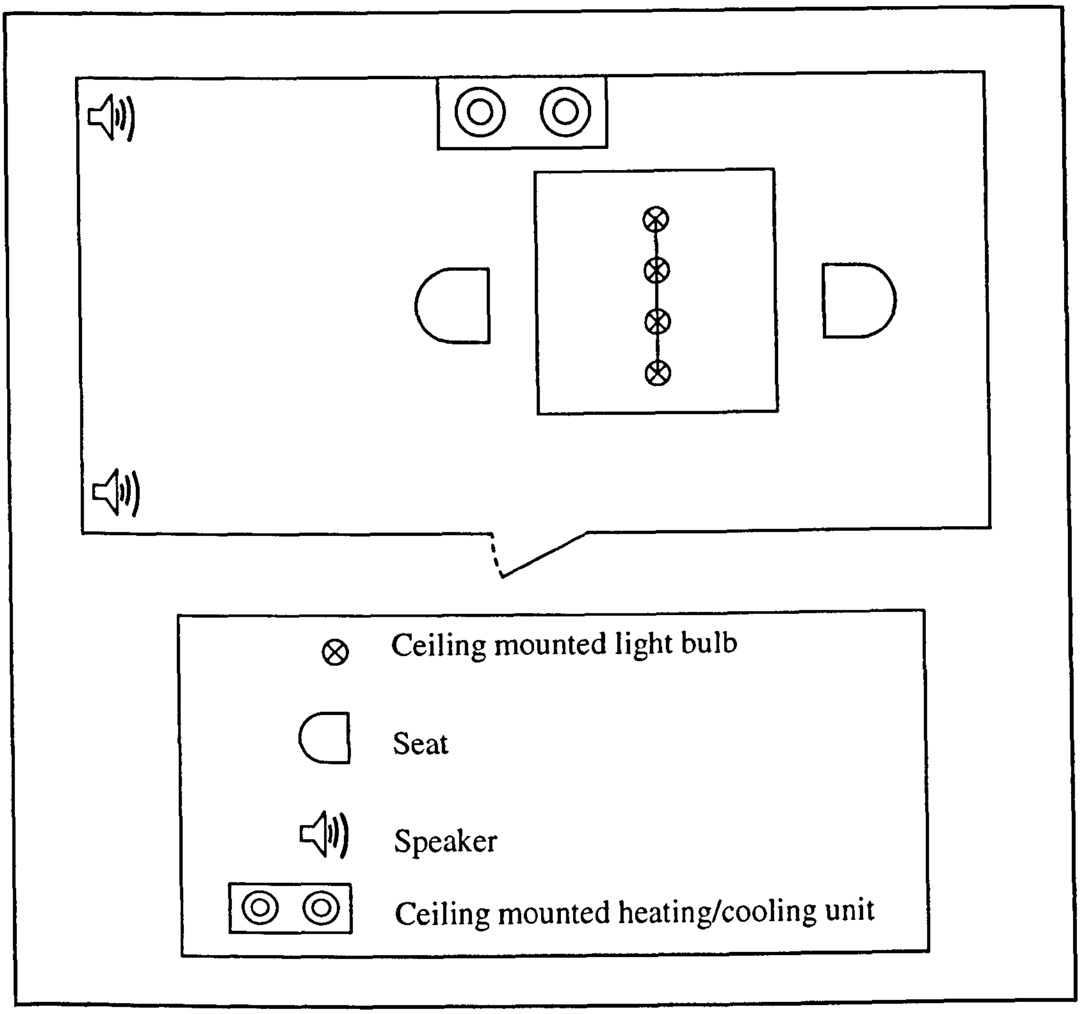


Figure 6-9 Schematic diagram of the test chamber

The chamber functions as an environmentally controllable unit, where temperature can be thermostatically controlled by means of a ceiling mounted chilling and heating system. The chamber has a concrete floor and heavily thermally insulated walls. Figure 6-10 shows the heating and chilling unit installed in the chamber. The unit was switched off for the duration of each session test, to control noise. The chamber is sufficiently well insulated to maintain temperatures in the range of investigation for 40 minutes.

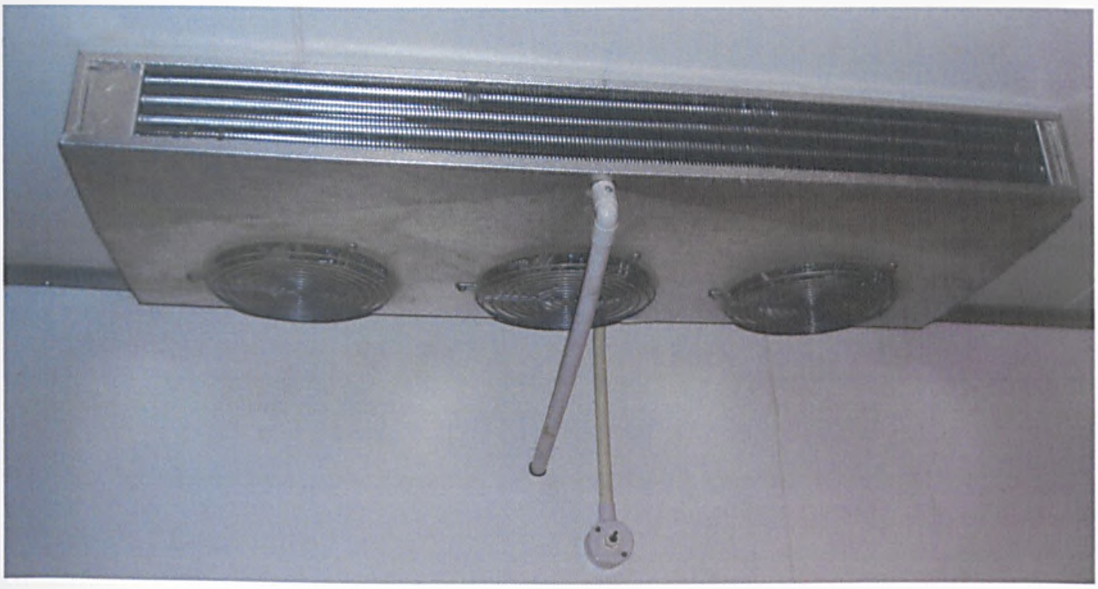


Figure 6-10 Cooling unit

Measurements of temperature and relative humidity were made at the seating position at the participant's desk in the room. Both were measured at the start and end of each testing session to ensure accuracy and monitor change.

A ceiling mounted luminaire with four incandescent bulbs was installed directly over the desk to supply lighting (Figure 6-11). A dimmer switch permitted the lights to be raised or lowered to achieve the various lighting levels. Measurements of illumination were made on the working plane, in accordance with the CIBSE Code for Lighting, as recommended by Forster (1997). This technique requires a theoretical grid to be applied to the working space, and the average is taken of the illuminances at grid intersection points.

As the working area is a relatively small area, covering less than the area of the desk, a 50 x 50cm square grid was used, with intersections 25 cm apart, comprising nine measurement points in total.

Figure 6-11 Luminaire

The chamber was thoroughly cleaned, floored with carpet tiles and decorated with posters to make the room more representational of a study area (Figure 6-12).

Figure 6-12 Environmentally controllable chamber

Two speakers placed on the floor at two corners of the room provided the source of background noise. A laptop computer was used by the experimenter to control playback. The background noise was recorded specifically for the purposes of this test. A base of traffic noise was mixed with a range intermittent sounds that would normally be heard in a classroom environment, such as coughing, scraping chairs, doors closing, rustling paper and pens. As with the preliminary study, human speech was deliberately excluded from investigation, due to its highly complex effects on human performance and attention.

The noise spectra can be seen below (Figure 6-13). The background noise proved to be extremely realistic, with several subjects commenting that they had not realised that they were listening to a recording until it was switched off at the end of the session.

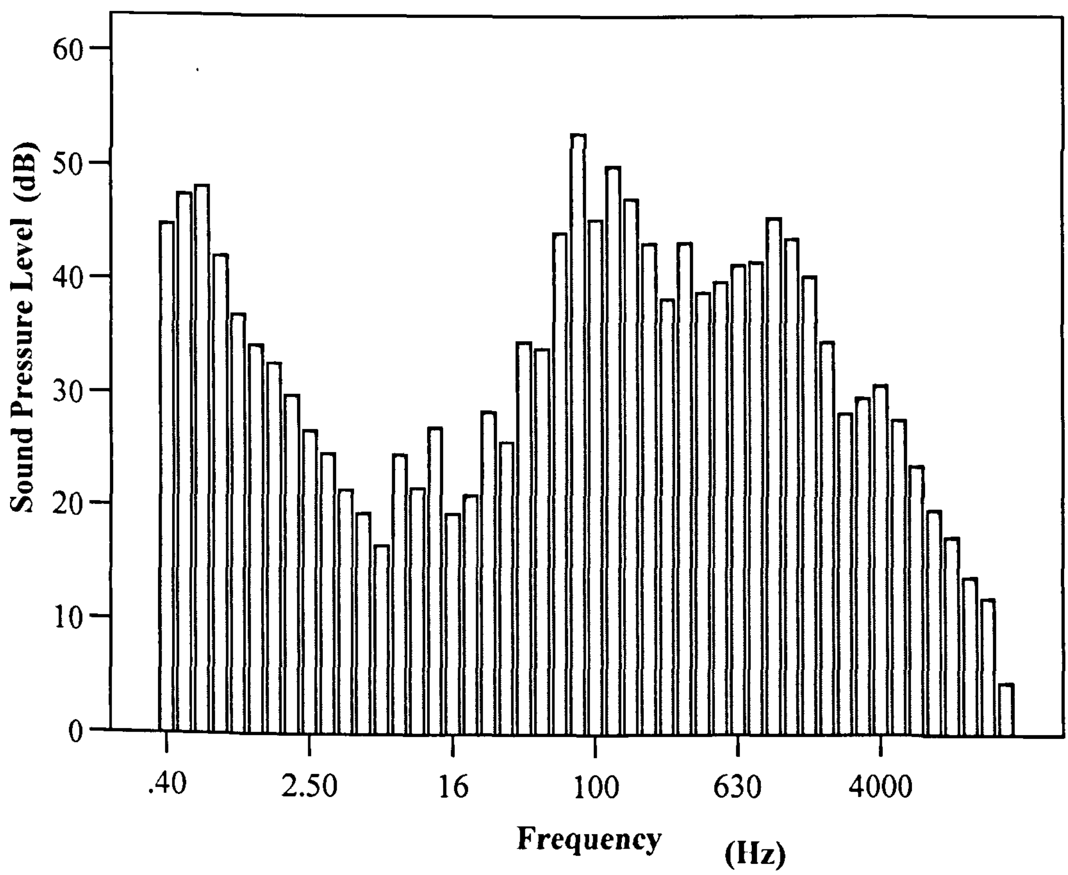


Figure 6-13 Unweighted L_{EQ} Spectrum of Background Noise

The average A weighted sound pressure level (L_{Aeq}) of the original recording was measured over its length, using the same audio equipment as to be used in experimentation, to provide a reference value. The volume of playback could then be adjusted to provide the required sound pressure levels for the experiments. This ensures that the effects of different playback equipment (i.e. speakers) on sound pressure level are avoided. L_{Aeq} was measured in the chamber, at approximately ear level for an individual seated at the desk. This ensures that the effects of room acoustics and position within the room are controlled.

The d2 test requires a signal to be given to start the test, and subsequent signals every twenty seconds to prompt a change of line. A beeping noise was used for this purpose, which was emitted from the same source as the background noise. The same signal was also used to indicate the start and finish of the Word Fluency tests. The beep was demonstrated to the students in the chamber before testing commenced during the brief acclimatisation period.

6.6.2 Testing Procedure

Respondents were both undergraduate and postgraduate students, across a range of ages and year groups. Students volunteered to participate in experiments, and were told that they their results would be available should they wish to compare them with peers, to provide a moderate level of motivation. They were not informed of the purpose of the experiment. To ensure that the effects of clothing on thermal comfort were controlled, volunteers were asked to arrive wearing a t-shirt and jeans, representing typical apparel for lectures.

Volunteers filled in forms giving personal details and were briefed on testing procedure in the chamber. This serves as a brief period of acclimatisation, lasting five minutes. Students then completed the Bond Lader assessment, followed by the d2 test of attention and the three word fluency tests. A one minute break was given between tests. Students were in the chamber for a total of thirty minutes.

6.7 Summary

This chapter has addressed several key methodological issues: the choice of test battery; experimental design; motivation and learning effects. The exploratory study demonstrated that the d2 test is vulnerable to the effects of repeated administration, and the experimental design has therefore been chosen which required each individual to only complete the test once. Use of a full factorial design with the three environmental variables examined at three levels gives an opportunity to investigate interactions between the variables, as well as gather evidence in respect of the inverted-U hypothesis of performance.

Use of the d2 test of attention ensures that a core underlying aspect of performance is being assessed, in addition to the more complex mental processes required by the word fluency assessment. The Bond Lader mood assessment is a more precise and flexible measure of mood than those which have been used to date in similar studies, and its inclusion will provide valuable information about its use for others.

Chapter 7: Results

7.1 Strategy for analysis

This chapter examines the results of experimentation described in Chapter 6. Before examining the effects of the environmental variables on performance, a number of preliminary analyses have been carried out to ensure that the tests have been scored correctly, and that the full factorial design has been successful. This is followed by a series of analyses which examine the effects of temperature, noise and lighting on mood and performance.

7.2 Validation of d2 scores, mood assessment and environmental parameters

The d2 test and Bond Lader mood assessment are each measured by a number of scores, some of which intercorrelate. Similarities in structure between previously published results and the results of this study indicate that the tests have been correctly administered and scored. Such similarities are described in this section.

The results of the Environmental VAS included in the test battery can be used as indicator that the levels chosen for lighting, noise, and temperature, create significantly difference environments. If the levels of each environmental variable have been set suitably far apart there should be a trend of predictable responses to the environment. If these are measurable it is indicative of the experimental design being successful. This forms the third and final part of the validation of the procedure and parameters of testing.

7.2.1 Intercorrelations of d2 test scores

The d2 test is a commercially marketed psychological test, accompanied by a manual giving directions for use (Brickenkamp and Zillmer 1998). The manual includes gives a variety of norms for the d2 test, one being a table of statistically significant correlations between the various scores of the d2 test for a sample of 506 American college students. This has been reproduced in Table 7-1.

Correlations in the d2 manual are not given with exact significance levels, other than values of $p>0.05$ being marked as insignificant. A similar table has been composed for scores gathered in the course of this study, shown in Table 7-2.

For both the reference study and the present study there is no significant correlation between speed of performance and the number of errors made on the d2 test. The E% scores correlates strongly with E ($p<0.01$), and not with TN, for both studies showing that E% scores are weighted towards errors rather than speed of performance. This is expected, as E% is a relative measure of E.

In both cases the CP score is correlated with both errors and speed of performance ($p<0.01$), indicating that it may be a more reliable way of measuring overall performance than E%.

There was a difference in the relationship between TN-E and its constituent raw scores TN and E, between the studies. In both instances TN-E is correlated with speed of performance (TN), but where Brickenkamp also finds a correlation with E errors, no such correlation has been found in the present study. It should be noted that the correlation between TN-E and E is described as "low/moderate" by Brickenkamp. The larger sample size used by Brickenkamp, and differences in proportions of E within the TN-E score could account for this difference between studies.

In a similar manner FR scores are linked to both errors and speed of performance by Brickenkamp, but are only correlated with error rates in this study. Again, the correlation between FR and TN is described as being of "low/moderate" significance, meaning that sample size and characteristics of TN between groups could affect significances of the correlation.

Table 7-1 Correlations between d2 scores from manual

	TN	TN-E	CP	E	E%
TN-E	r = 0.95 *high /very high*				
CP	r = 0.72 *moderate /high*	r = 0.89 *very high*			
E	- *not significant*	r = 0.32 *low /moderate*	r = -0.65 *moderate /high*		
E%	- *not significant*	r = 0.42 *moderate*	r = -0.72 *moderate /high*	r = 0.99 *high /very high*	
FR	r = -0.37 *low /moderate*	r = -0.47 *moderate*	r = -0.52 *moderate*	r = 0.34 *low /moderate*	r = 0.38 *low /moderate*
r = Pearson's coefficient of correlation, and N=506 for all correlations					

Table 7-2 Statistically significant intercorrelations of d2 scores

	TN	TN-E	CP	E	E%
TN-E	r = 0.975 **				
CP	r = 0.887 **	r = 0.964 **			
E	-	-	r = -0.374 **		
E%	-	r = -0.306 **	r = -0.522 **	r = 0.976 **	
FR	-	-	r = -0.213 *	r = 0.279 **	r = 0.288 **
r = Pearson's coefficient of correlation, where N=129 for all correlations					
*** Correlation is significant at the 0.01 level*					
** Correlation is significant at the 0.05 level*					

Other than these differences between TN-E and E, and FR and TN, intercorrelations between the scores are similar in nature, suggesting that the test has been correctly scored and administered.

The lack of a correlation between error rate and speed show that arguments made in the literature review about the importance of measuring both these facets of performance have been upheld. Integrated overall performance scores should be applied with caution, as TN-E and CP scores are heavily biased by either TN or E. Using separated E and TN scores is therefore preferable. If a measure of overall performance is required CP is the most appropriate measure for use, being correlated to both speed and performance.

7.2.2 Analysis of common mood factors

The mood assessment used has been extracted from a 1974 study by Bond and Lader (1974). Bond and Lader extracted the common factors present in the 16 scales, using the data from mood assessments completed by 500 subjects. Bond uses factor analysis to extract three factors from the data, arbitrarily named alertness, contentedness and calmness. Replicating this method of data reduction provides a basis for comparison between the studies, to ensure the test has been correctly administered and scored.

A frequency distribution is computed and plotted for each scale in the same manner as Bond (Appendix 7 A). To ensure that subjects have completed the scale correctly, and have not completed the Bond Lader assessment superficially by consistently marking down the middle, the number of scores between 45 and 55 mm for each subject have been extracted and plotted as a frequency histogram, as shown in Figure 7-1.

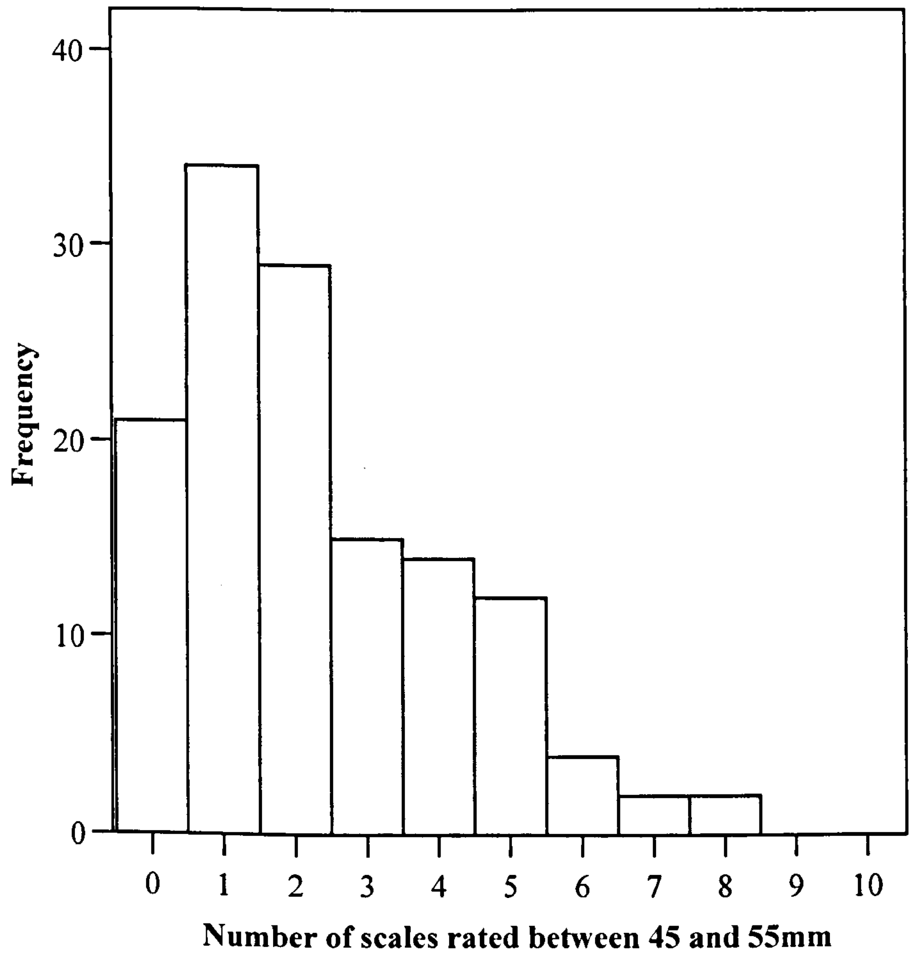


Figure 7-1 Number of scales rated between 45 and 5mm for each subject

Most individuals only marked a scale in the middle either once, twice or not at all. A few subjects rated seven or eight scales in the middle, less than half of the scales included in the assessment.

As results are to be compared with Bond's, the data is prepared in the same manner. In both studies some scales have an asymmetrical distribution of scores. Table 7-3 shows measured skew for each variable, with negatively skewed scale highlighted. The same scales were found to display negative skew in both studies.

Table 7-3 Table of skew for each element of the Bond Lader scale

Scale	Skew
Alert - Drowsy	0.553
Calm - Excited	0.338
Strong - Feeble	0.546
Muzzy - Clearheaded	***-0.612***
Well Coordinated - Clumsy	0.401
Lethargic - Energetic	***-0.099***
Contented - Discontented	0.631
Troubled - Tranquil	***-0.367***
Mentally Slow – Quick Witted	***-0.398***
Tense – Relaxed	***-0.560***
Attentive – Dreamy	0.153
Incompetent - Proficient	***-0.496***
Happy – Sad	0.678
Antagonistic - Friendly	***-0.840***
Interested – Bored	0.853
Withdrawn - Sociable	***-0.786***

Bond reverses scales displaying negative skew, so that the entire data set shows the same direction of asymmetry. For consistency, the same process has been applied, so that 'Muzzy – Clearheaded' becomes 'Clearheaded –Muzzy', 'Lethargic - Energetic' becomes 'Energetic – Lethargic', and so on. Bond then applies a natural log transformation, which can be seen in comparison with the identically treated data from this study in Table 7-4. It can be seen that means and standards deviation are broadly similar to Bond's.

Table 7-4 Means and Standard Deviations on scales after $\log_e$ transformation for both data sets

			Bond (1974)	
Scale	Mean	Std. Dev	Mean	Std. Dev
Alert – Drowsy	3.26	0.83	3.60	0.80
Calm – Excited	3.28	0.10	3.22	0.94
Strong – Feeble	3.25	0.77	3.68	0.68
Clearheaded – Muzzy	3.46	0.73	3.55	0.80
Well Co-Ordinated - Clumsy	3.37	0.79	3.37	0.80
Energetic – Lethargic	3.73	0.52	3.80	0.64
Contented - Discontented	3.40	0.81	3.31	0.98
Tranquil - Troubled	3.45	0.82	3.46	0.83
Quick Witted – Mentally Slow	3.60	0.57	3.72	0.59
Relaxed - Tense	3.48	0.76	3.43	0.76
Attentive - Dreamy	3.57	0.67	3.60	0.75
Proficient - Incompetent	3.39	0.63	3.62	0.58
Happy - Sad	3.11	0.91	3.23	0.96
Friendly - Antagonistic	3.00	0.93	3.20	0.88
Interested - Bored	2.98	0.96	3.36	0.87
Sociable - Withdrawn	3.19	0.91	3.61	0.67

Bond then applied a factor analysis, a process which detects the structure of a number of variables. It assesses whether the variables can be explained largely or entirely in terms of a smaller number of weighted variables, termed factors (Streiner and Norman 2005). This process is known as extraction. Factor analysis allows the 26 scales of the Bond Lader test to be reduced to a smaller number of factors, which can be described as facets of mood.

Bond's method of factor analysis used a principle component solution, and an orthogonal rotation of the factor matrix. Restricted by computer processing abilities, Bond would have been unable to use the more sophisticated methods of analysis available today. Recent research, i.e. Costello and Osborne (2005) argues in favour of the use of methods such as maximum likelihood (ML) or Principle Axis Factoring (PAF) to extract factors, depending on the normality of the data. In order for the analysis to not differ too far from Bond's original method, the assumption of normally distributed data is retained, for which ML analysis is the most appropriate technique.

The technique to gauge the number of factors for retention has traditionally been to retain factors with an eigenvalues of unity or more. Bond followed this methodology. Costello highlights the concern that this technique often results in too many factors being retained, and instead recommends using a scree test, which graphs eigenvalues, using the point at which the graph flattens out or 'breaks' to identify the number of factors for retention.

Bond's choice of an orthogonal rotation is a common one, with Costello noting that they are often considered to "produce more easily interpretable results". Costello further explains that orthogonal rotation is found to lose information where factors are correlated, and any type of oblique rotation should produce a more accurate solution.

In order to be relevant to current and future research, the more modern approach to factor analysis has been taken. The factor analysis applied to the data used a ML method of extraction is conjunction with an oblique method of rotation (Promax). A scree test was generated to identify the number for factors for extraction (Figure 7-2).

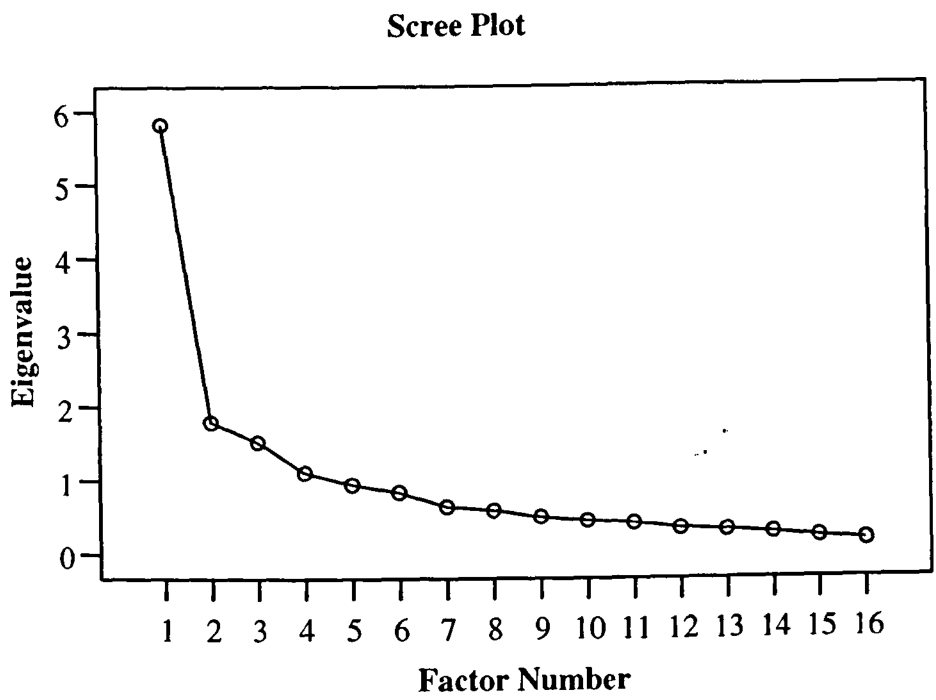


Figure 7-2 Scree plot of mood scales

The scree plot indicates that four factors should be retained for analysis. Examining the item loading labels for four factors, however, showed an incomplete loading structure, where the fourth factor had only one variable loaded. This was corrected by reducing the number of factors to be extracted to three, and reapplying the analysis. Bond also found three factors. Correlations between each variable and factor are shown in a factor loading matrix (Table 7-5).

The strongest loading for each item is highlighted. The table shows a good fit for the data, with each factor being composed of more than three factors, item loadings greater than 0.3, and minimum cross loading, in accordance with Costello's criteria for reliability. Table 7-6 shows the loading of each Bond Lader scale onto the three factors.

Table 7-5 Factor Loading Matrix

	Factor		
	1	**2**	**3**
Alert – Drowsy	0.254	***0.453***	0.134
Calm – Excited	0.071	0.083	***0.618***
Strong – Feeble	0.472	***0.592***	0.333
Clearheaded – Muzzy	0.302	***0.485***	0.359
Well Co-ordinated - Clumsy	0.364	***0.568***	0.307
Energetic – Lethargic	0.371	***0.468***	0.122
Contented - Discontented	0.496	0.396	***0.654***
Tranquil - Troubled	0.549	0.405	***0.639***
Quick Witted – Mentally Slow	0.376	***0.726***	0.195
Relaxed - Tense	0.326	0.337	***0.800***
Attentive - Dreamy	0.357	***0.626***	0.227
Proficient - Incompetent	0.588	***0.762***	0.381
Happy - Sad	***0.909***	0.439	0.307
Friendly - Antagonistic	***0.834***	0.575	0.403
Interested - Bored	***0.693***	0.496	0.288
Sociable - Withdrawn	***0.770***	0.529	0.348

Table 7-6 Three mood factors

Factor 1 *(Alertness)*	Alert – Drowsy	*0.453*
	Energetic – Lethargic	*0.468*
	Clearheaded – Muzzy	*0.485*
	Well Co-ordinated - Clumsy	*0.568*
	Strong – Feeble	*0.592*
	Attentive - Dreamy	*0.626*
	Quick Witted – Mentally Slow	*0.726*
	Proficient - Incompetent	*0.762*
Factor 2 *(Gregariousness)*	Interested - Bored	*0.693*
	Sociable - Withdrawn	*0.770*
	Friendly - Antagonistic	*0.834*
	Happy - Sad	*0.909*
Factor 3 *(Calmness)*	Calm – Excited	*0.618*
	Tranquil - Troubled	*0.639*
	Contented - Discontented	*0.654*
	Relaxed - Tense	*0.800*

Factor 1 shows very similar characteristics to Bond's 'Alertness' factor, the only difference being that 'Interested – Bored' has moved to Factor 2. Factor 1 has been given the same descriptive title 'Alertness'.

Factor 2 contains many of the variables seen in Bond's 'Contentedness' factor, with the exception of two scales; 'Contentedness – Discontentedness' and "Troubled – Tranquil', now found in Factor 3. This poses a problem for the naming of the factor in the same manner as Bond, as the 'Contentedness – Discontentedness' scale is no longer present. Factor 2 has therefore been renamed 'Gregariousness'.

Factor 3 is Bond's 'Calmness' factor, with the addition of 'Contentedness – Discontentedness' and "Troubled – Tranquil', and the title has been retained.

Factor analysis of the data has shown sufficient similarity to the structure of Bond's data for subjects to be regarded as interpreting the meaning of the individual scales in the same manner. The small differences present could be due to natural differences between sampling populations, as well as the differing methods of analysis.

A further analysis was carried out to compare the results of the Bond Lader mood assessment and the traditional single line overall mood VAS.

As the data is not normally distributed, Spearman's r_s has been employed to measure the degree of relationship between two variables. Spearman's r_s is calculated by ranking sample data separately for each variable, and using the formula:

$$r_s = 1 - \frac{6\sum d^2}{n^3 - n} \tag{7-1}$$

where r_s is the symbol for the sample value of Spearman's coefficient of rank correlation, and $\sum d^2$ means the sum of the squares of the differences in the ranks of the n individuals (Rees). A non-parametric hypothesis test may then be carried out.

When n is 10 or more, we can find a function of r_s which is distributed approximately as a t-statistic, and it can be shown that

$$r_s\sqrt{\frac{n-2}{1-r_s^2}} \tag{7-2}$$

is approximately t with n -2 degrees of freedom (Clarke and Cooke 2004).

Magnitudes of r_s may vary between minus one and one. If $r_s = 1$ there is perfect agreement in the rankings, and if $r_s = -1$, there is perfect disagreement. If $r_s = 0$, a particular rank for one variable may correspond with any rank for the other variable, and there is no relationship between the variables.

Using this method, it can be seen that every Bond Lader item but 'Calm – Excited' is a statistically significant correlate of the overall mood VAS (Table 7-7). The degree of correlation are all positive, varying between about r_s = 0.2 and r_s = 0.5, which can be interpreted as explaining in the region of 4% to 25% of the variation (Owen and Jones 1993).

These results show that a simple mood VAS is capable of being used to give an overall assessment of mood. However, it is interesting that 'Calm – Excited' is not a correlate of overall mood, and yet 'Alert – Drowsy' is a highly significant correlate, as these are both terms which could be considered to be descriptive of states of arousal. This type of disparity demonstrates the importance of using a sufficiently detailed mood assessment, such as the Bond Lader scale, giving an opportunity to examine the various facets of mood rather than treating it as a universal variable.

Table 7-7 Bond Lader assessment and traditional VAS

		Best Mood – Worst Mood
Alert – Drowsy	r_s	**0.327***
Energetic – Lethargic	r_s	**0.251***
Clearheaded – Muzzy	r_s	**0.330***
Well Co-ordinated - Clumsy	r_s	**0.291***
Strong – Feeble	r_s	**0.317***
Attentive - Dreamy	r_s	**0.354***
Quick Witted – Mentally Slow	r_s	**0.299***
Proficient - Incompetent	r_s	**0.409***
Interested - Bored	r_s	**0.353***
Sociable - Withdrawn	r_s	**0.444***
Friendly - Antagonistic	r_s	**0.506***
Happy - Sad	r_s	**0.418***
Calm – Excited	r_s	-0.032
Tranquil - Troubled	r_s	**0.291***
Contented - Discontented	r_s	**0.406***
Relaxed - Tense	r_s	**0.204****
N=129 for all correlations		
*** Correlation is significant at the 0.01 level*		
** Correlation is significant at the 0.05 level*		

7.2.3 Sensation of the Environment

The results of the Environmental VAS can be used as a check to ensure that the levels for each environmental variable have been set suitably far apart to create discernable differences in the environment. Even though subjects only experienced one environment, there should be a measurable trend of cold environments being rated as cold, higher working plane illuminances being rated as bright, and so on.

This data is again non-parametric, and Spearman's r_s has again been employed to measure the degree of relationship between two variables. Strong correlations were found between physical measures of temperature, lighting and background noise, and respondent's perceptions of those variables as measured by the Environmental VAS, all strongly significant at the $p<0.001$ level (Table 7-8).

Table 7-8 Environmental variables and environmental assessment

Environmental VAS	**Temp (°C)**	**Noise (dBA)**	**Light (Lux)**
Too Hot - Too Cold	***-0.842*****		
Too Noisy - Too Quiet		***-0.793*****	
Too Bright - Too Dark			***-0.523*****
Best Comfort - Worst Comfort	-0.119	0.135	-0.137
N=133 for all correlations			
*** Correlation is significant at the 0.01 level*			

These correlations show that the subjects reacted to the environment in exactly the manner expected to the environmental variables. Figure 7-3 illustrates the responses to the temperature EVAS graphically, where each individual is represented by a single point. The individuals were almost unanimous in declaring the 30°C condition to be somewhere in the 'too hot' region, with a single individual marking it as being on the cold side of the scale. The EVAS has no marking at the centre, and this individual may have misjudged the halfway point on the scale, or simply have fairly unique temperature preferences. Generally, there is a trend of increasing temperature provoking more responses in the 'too warm' region, and colder temperatures provoking more 'too cold' responses.

Figure 7-3 can be considered in the context of temperature requirements for schools. The minimum wintertime heating requirement, represented by the 17-18°C condition is clearly considered by most students to be too cold. Likewise, the 30°C condition, representing the maximum summer overheating temperature is considered by most to be too hot.

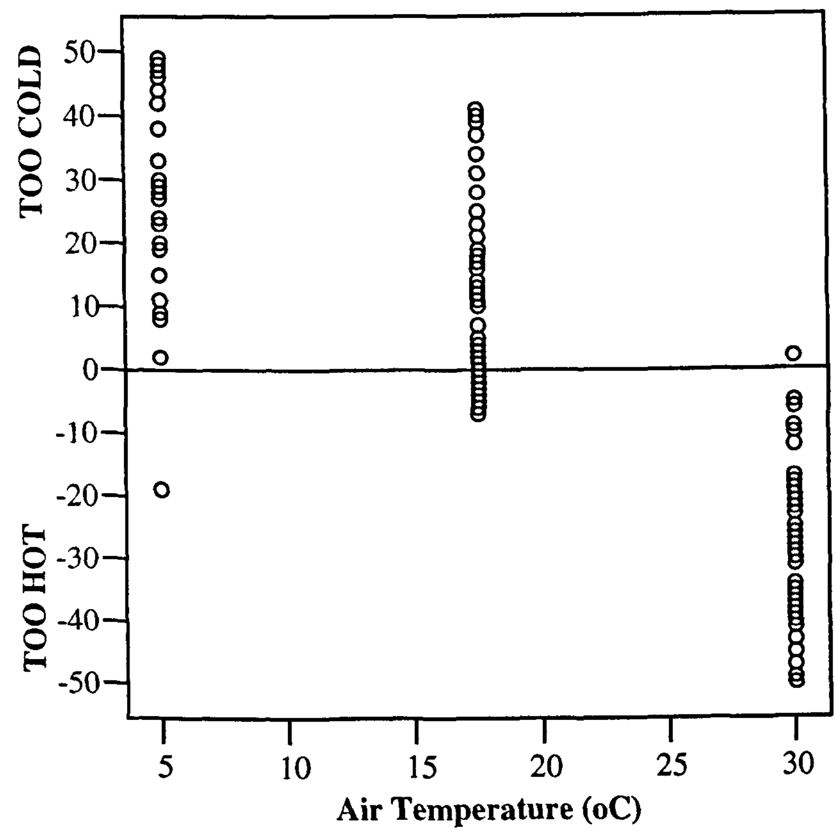


Figure 7-3 EVAS and temperature

Figure 7-3 has been replicated for lighting and noise in Figure 7-4 and Figure 7-5 respectively. These illustrate similar patterns, where subjects respond to the environmental variables in the manner expected; criticisms of darkness increase with falling working plane lighting levels, and criticisms of noise increase with sound pressure level.

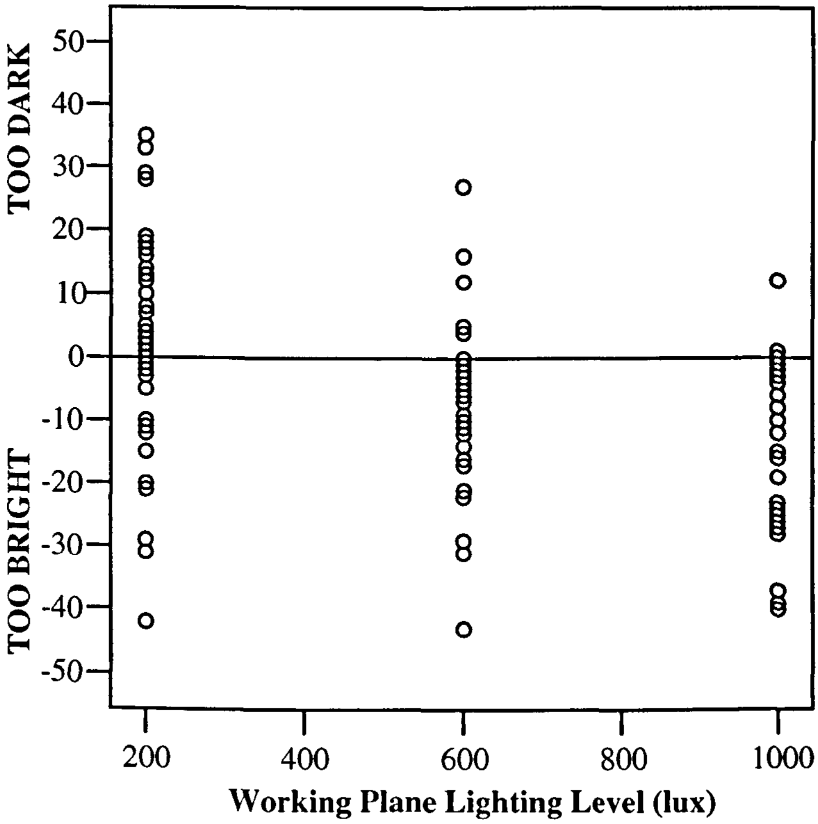


Figure 7-4 EVAS and Working Plane Lighting Level

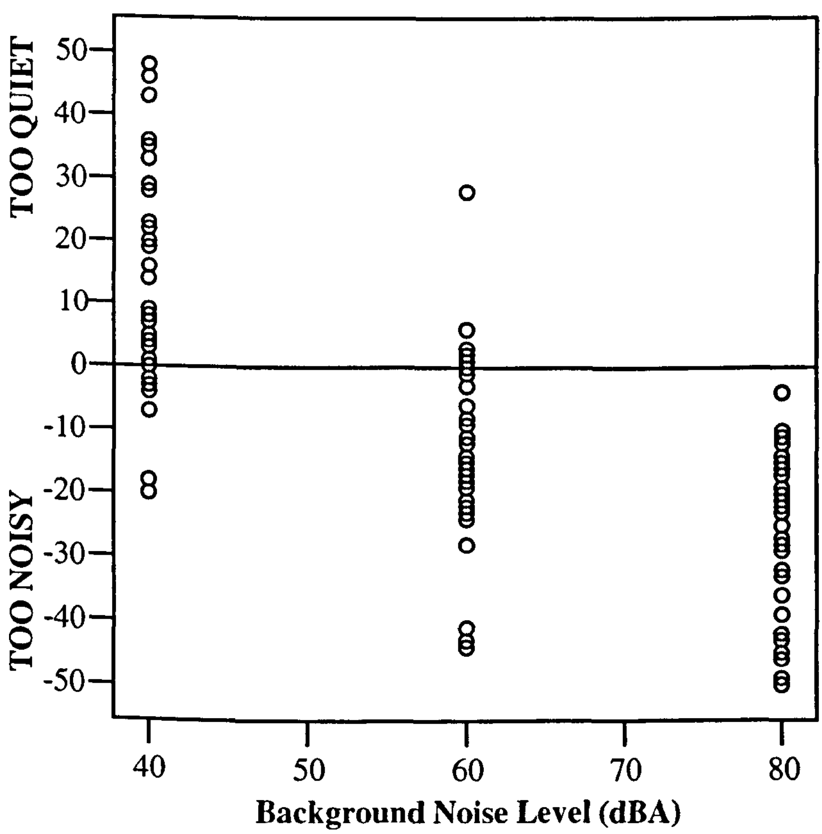


Figure 7-5 EVAS and Background Noise Level

Examination of the 'Best Comfort – Worst Comfort' scale shows no correlation with the environmental variables, despite the previous responses made. This is not entirely unexpected, as factors such as the décor of the room and comfort of the furniture will be of importance when making judgements of overall comfort. To more fully explore the nature of overall comfort, the scale was correlated with the subjective assessments made of the environment by respondents (Table 7-9)

Table 7-9 Assessment of environmental variables and overall comfort

	Too Hot - Too Cold	**Too Bright - Too Dark**	**Too Noisy - Too Quiet**
Best Comfort - Worst Comfort	*0.263***	0.132	-0.118
N=133 for all correlations			
** *Correlation is significant at the 0.01 level*			

Comparison of Table 7-8 and Table 7-9 shows that of the variables measured, only thermal comfort is a correlate of overall comfort. The subjects did not significantly take the noise and lighting, or their effects into account when making assessments of overall comfort. Temperature has the most pronounced physiological effects on the body of the three environmental variables within the ranges under investigation. The temperature range of 5 to 30°C represents fairly hot and cold conditions, and so subjects may have been annoyed specifically by the temperature when completing their overall comfort assessments.

The correlation between overall comfort and thermal comfort, but not between overall comfort and air temperature, provides evidence for the mediating effects of individual response to environmental variables. This has been illustrated in each of the models of stress and strain described in the literature review.

This makes the Environmental VAS useful as independent variables in conjunction with the physical measures of the environment, by measuring the relative effect of human response to each variable on performance and mood.

7.3 Environment, mood and performance

Previous sections have demonstrated the validity of the tests used, and shown that the experimental design yields measurable results. This section examines interactions between the environmental variables, mood, and performance.

7.3.1 Environment and mood

Correlations between the environmental variables and each item on the Bond Lader mood scale are shown in Table 7-10 on the following page, arranged by the factors which were previously extracted.

No significant correlations were found between any aspect of mood and light or temperature. Background noise is however associated with many of the items on the Bond Lader mood assessment. Sound pressure level correlates with at least one item from every factor. The relationship between sound pressure level and Factor 3, Calmness, is of particular interest, as three of the four items loaded onto the scale show a weak, but statistically significant correlation with noise level. The positive correlations show that individuals report increased feelings of being troubled, excited, and tense with increased sound pressure levels, as well as muzzy, slow and withdrawn.

This format has been replicated to show correlations between the results of the EVAS and the Bond Lader Mood Assessment, in Table 7-11 shown in the following pages.

Table 7-10 Table of correlations (r_s) between environment and mood

Factor	Mood Scale	Temp (°C)	Noise (dBA)	Light (Lux)
Factor 1 *(Alertness)*	Alert – Drowsy	-0.077	-0.058	-0.076
	Energetic – Lethargic	-0.035	0.125	-0.020
	Clearheaded – Muzzy	0.129	***0.189****	0.024
	Well Co-ordinated – Clumsy	0.039	-0.060	-0.032
	Strong – Feeble	-0.093	-0.018	-0.167
	Attentive - Dreamy	-0.012	0.054	-0.050
	Quick Witted – Mentally Slow	-0.010	***0.231*****	-0.044
	Proficient - Incompetent	-0.014	0.131	-0.033
Factor 2 *(Gregarious)*	Interested - Bored	0.124	0.126	0.112
	Sociable - Withdrawn	0.029	***0.252*****	-0.036
	Friendly - Antagonistic	-0.085	0.069	-0.088
	Happy - Sad	-0.048	0.033	-0.049
Factor 3 *(Calmness)*	Calm – Excited	-0.003	***0.209****	0.041
	Tranquil - Troubled	-0.066	***0.221*****	-0.027
	Contented - Discontented	-0.093	0.170	-0.078
	Relaxed - Tense	0.102	***0.231*****	0.080

*** Correlation is significant at the 0.01 level*

** Correlation is significant at the 0.05 level*

Table 7-11 Table of correlations (r_s) between EVAS assessment and mood

	Mood Scale	Too Hot – Too Cold	Too Noisy-Too Quiet	Too Bright – Too Dark	Overall Comfort
Factor 1 (*Alertness*)	Alert – Drowsy	0.127	0.083	0.123	0.150
	Energetic – Lethargic	0.074	-0.098	-0.057	0.066
	Clearheaded – Muzzy	-0.065	-0.129	-0.044	0.132
	Well Coordinated– Clumsy	0.088	0.059	0.109	-0.027
	Strong – Feeble	0.158	0.068	**0.207***	0.105
	Attentive - Dreamy	0.095	-0.059	0.153	0.043
	Quick Witted –Mentally Slow	0.070	**-0.187***	-0.069	0.165
	Proficient - Incompetent	**0.185***	-0.159	0.127	0.125
2	Interested - Bored	-0.018	-0.100	-0.026	**0.240****
	Sociable - Withdrawn	-0.042	-0.159	0.038	**0.244****
	Friendly - Antagonistic	0.129	0.000	0.164	**0.261****
	Happy - Sad	0.106	0.064	0.156	**0.293****
3 (*Calmness*)	Calm – Excited	0.063	-0.143	-0.003	0.142
	Tranquil - Troubled	0.140	-0.163	0.080	**0.251****
	Contented - Discontented	0.151	-0.063	0.135	**0.233****
	Relaxed - Tense	0.098	**-0.214***	-0.055	**0.341****

*** Correlation is significant at the 0.01 level*

** Correlation is significant at the 0.05 level*

The results of this analysis show minimal effects of luminous and thermal comfort on mood, with only a single scale showing significant correlations at the $p<0.05$ level.

Most interestingly, assessments of noisiness/quiet correlate with only a single scale of the Bond Lader Mood Assessment, 'Quick Witted – Mentally Slow'. This is a marked difference to the effects of Sound Pressure Level, which correlated with six scales. This is unexpected, as these measures of noise and noise stress are closely correlated, as detailed earlier, and as such would be expected to have similar effects on mood.

7.3.2 Environment and performance

The data was examined for correlations between the environment and performance on the d2 test and word fluency tests. No statistically significant correlations were found between the environmental variables and speed of performance, measured by TN (Appendix 7 B), or consistency of performance, measured by FR (Appendix 7 C). A weak correlation exists between errors of omission (E1) and working plane lighting level ($p<0.05$) (Table 7-12), where error rates decrease as lighting levels increase.

Table 7-12 Correlations (r_s) between environment and errors in performance

	Temp (°C)	Noise (dBA)	Light (Lux)
E1	0.012	-0.059	***-0.218****
E2	-0.032	0.095	-0.113
N=129 for all correlations			
* Correlation is significant at the 0.05 level			

The environmental assessment results from the Environmental VAS were then examined for correlations with performance. No correlation was found between subjective assessments of the environment and speed of performance (Appendix 7 D), errors (Appendix 7 E) or consistency of performance (Appendix 7 F).

Table 7-13 shows correlations between the environmental variables and the results of the three word fluency tests.

Table 7-13 Correlations (r_s) between environment and word fluency

	Temp (°C)	Noise (dBA)	Light (Lux)
WF1	-0.086	-0.053	-0.124
WF2	-0.101	-0.095	-0.116
WF3	-0.026	-0.044	**-0.183***
* Correlation is significant at the 0.05 level			

Another weak correlation can be seen between working plane lighting level and performance on the third test (WF3) ($p<0.05$), where scores on the third word fluency test decrease with increases in the brightness of light.

When the word fluency test was used by Hygge, Boman et al. in 2003 a significant difference was found between road traffic noise at 66 dBA, and no noise, on the third part of the word fluency test. This result has not been replicated in this study, with no significant correlations identified between word fluency test results and noise conditions.

A slightly stronger relationship is seen again between assessment of brightness and WF3 ($p<0.05$), as seen in Table 7-14, where assessments of increased brightness are weakly correlated with decreased WF3 scores.

Table 7-14 Correlations (r_s) between EVAS and Word Fluency

	Too Hot – Too Cold	Too Noisy – Too Quiet	Too Bright – Too Dark	Best – Worst Comfort
WF1	-0.040	0.067	-0.060	-0.080
WF2	-0.041	0.018	0.012	-0.053
WF3	0.130	0.092	**0.202***	-0.121
* Correlation is significant at the 0.05 level				

7.3.3 Mood and performance

No correlations were found between speed of performance and any of the items on the Bond Lader mood assessment (Appendix 7 G), or the two additional variables related to hunger and overall mood (Appendix 7 H).

A single correlation was found between errors of commission (E2), and the 'Attentive – Dreamy' item on the Bond Lader assessment (Table 7-15). The remaining non-significant correlations between the remainder of the Bond Lader mood assessment and Word Fluency are shown in Appendix 7 M. Strongly significant correlations at the p<0.01 level exist between all Word Fluency test results, and students' overall self assessment of mood (Table 7-16). The negative correlations show that performance on the Word Fluency tests drop as assessments of overall mood worsen.

This finding of an effect of mood on performance is an interesting addition to the work of Gawron (1984), discussed in section 2.4. Gawron, also using a background traffic noise, found that subjects rated both their mood and environment more negatively in the noisy condition. However, no reliable effects were found on performance. A very similar result is described in this chapter, where noise is a significant correlate of many aspects of mood, and noisy environments are rated as being more aurally distressing. Gawron finds no subsequent effects of mood or noise on performance.

The literature review attributed this to Gawron's use of a limited scoring system, where only 'correct answers' are counted. It postulates that performance should be regarded as being composed of a number of elements, speed and errors being of primary concern. The identification, in this study, of an association between errors and the 'Attentive – Dreamy' scale, supports that hypothesis. Had the overall measures TN or CP constituted the sole means of measuring performance no effect would have been measured.

No correlation was found between errors and the additional scales relating to hunger and overall mood or the Bond Lader mood assessment (Appendix 7 I and Appendix 7 J). No correlations were found between consistency of performance and the Bond Lader mood assessment (Appendix 7 K), or overall mood or hunger (Appendix 7 L).

Table 7-15 Correlations (r_s) between Bond Lader assessment and Errors

	E1	E2	E
Attentive - Dreamy	0.028	***-0.175****	0.009
N=129 for all correlations			
* Correlation is significant at the 0.05 level			

Table 7-16 Correlations (r_s) between Word fluency, hunger and overall mood

	WF1	WF2	WF3
Hungry – Full	0.167	0.115	-0.051
Best Mood – Worst Mood	**-0.278****	**-0.240****	**-0.218***
*** Correlation is significant at the 0.01 level*			
** Correlation is significant at the 0.05 level*			

Table 7-17 Correlations (r_s) between 'Calm-Excited' and Word Fluency

	WF1	WF2	WF3
Calm – Excited	**-0.176***	-0.128	0.008
* Correlation is significant at the 0.05 level			

7.4 Discussion

Analysis of the data gathered in the course of experimentation has shown that the tests were correctly administered and scored. Several significant interactions were identified between the tests and the environmental variables, demonstrating the suitability of a single-test experimental design for this type of research.

The Bond Lader test was found to be particularly useful for this type of study when combined with factor analysis. It has identified key differences in human responses to working plane lighting level, air temperature and background noise. Sound pressure level was found to correlate with several aspects of mood, particularly those loading onto the calmness factor. Light and temperature appeared to affect mood less, correlating only with 'strong-feeble' and 'proficient-competent' respectively. Perceptions of overall environmental comfort were found to be the most important to mood, correlating with a number of scales, especially those loading onto the gregariousness and calmness factors.

The most complex interaction between mood and the environment was observed with noise. The significant correlation between weighted sound pressure level in the chamber, and the 'noisy-quiet' EVAS rating, indicates that students recognised the relative 'loudness' of noise present. Students marked their mood as being more negative in the noisier conditions. As the 'noise' part of the EVAS gave opportunities for students to express displeasure with their acoustic environment, it was expected that the association between the acoustic EVAS and mood would be stronger. Instead, it was far less strongly associated with mood than sound pressure level alone.

These results suggest that sound pressure levels act on mood on a different level, where individuals may not find an environment particularly distressing, whilst nonetheless their feelings and attitude are being affected.

Lighting was found to be a significant correlate for various aspects of performance on both the attention task and the word fluency task. Less errors of concentration were made in the brighter conditions, but increased brightness also led to a tendency for lower word fluency scores.

The increase of errors in the d2 test of attention in the dimmer conditions could be attributed to visual function as well as to psychological effects, although the 200 lux provided is in excess of the 108 lux required by the Scottish School Premises Regulations. In practice, working plane illuminances should be in the region of 300 lux, the minimum as defined by the Building Bulletins.

Results of the word fluency tests showed that brighter conditions were associated with lower scores. Results of the word fluency test are particularly interesting, as the test can be considered as making demands on students comparable to writing an essay in exam conditions. The 'bright' condition of 1000 lux could easily be encountered in practise, most likely associated with either direct sunlight or harsh interior lighting schemes. As noted in Chapter Four, no maximum levels are currently in place for illuminances in classrooms. Further study on the effects of bright lighting is required in order to establish whether a benefit could be achieved from setting a standard for maximum illuminances in classrooms.

Analysis of the EVAS showed that individuals' assessments of temperature are correlated with reported overall comfort where sensations of brightness and noise are not. It is suggested that this indicates that air temperature is one of the most important variables for human comfort on initial exposure to an environment.

The literature review discussed the importance of choosing a test which yields an appropriate measure of performance, criticising those who only measured the speed of performance, or used a test which could only be scored in terms of errors. Results of the d2 test of attention showed no correlation between speed of performance, and the amount of errors which were made. This reinforces the argument for ensuring that test can be scored in terms of both speed and accuracy of performance.

Chapter 8: Conclusions

8.1 Discussion and Conclusions

Research examining cognitive effects of temperature, lighting and background noise in educational contexts has historically focussed on primary school children. This thesis is the first instance examining their effects on university level students. As such, the initial requirement was to examine the commonalities and disparities between their respective environments. This was achieved by identifying key differences in legislative approach, which constitute the basis for environmental provision in schools and universities as stated in the first aim of the research, i.e.

I. Investigate the role of building regulations, recommendations and guidelines in defining the classroom environment in schools and universities.

Reviewing the requirements for schools and universities highlighted key differences in legislative approaches to the control of the environments they provide. Where universities are subject to a minimum of legal requirements, new and existing schools are expected to comply with a more detailed body of legislation.

It is proposed that the structure of regulation as applicable to universities and schools can be described by Figure 8-1, a structure showing each layer of legislation. This clearly illustrates that universities are subject only to highly generalised environmental requirements in classrooms, in comparison to schools.

All workplaces are legally required to comply with the Workplace Health and Safety Regulations (1992), and the Control of Noise at Work Regulations (2005). These form the basis for environments in both schools and universities, constituting the only legal obligation in respect of levels of working plane lighting level, air temperature and noise in universities.

They detail very basic standards for the workplace, as shown in Table 8-1, which serve only to ensure that workers are not harmed by their work environment.

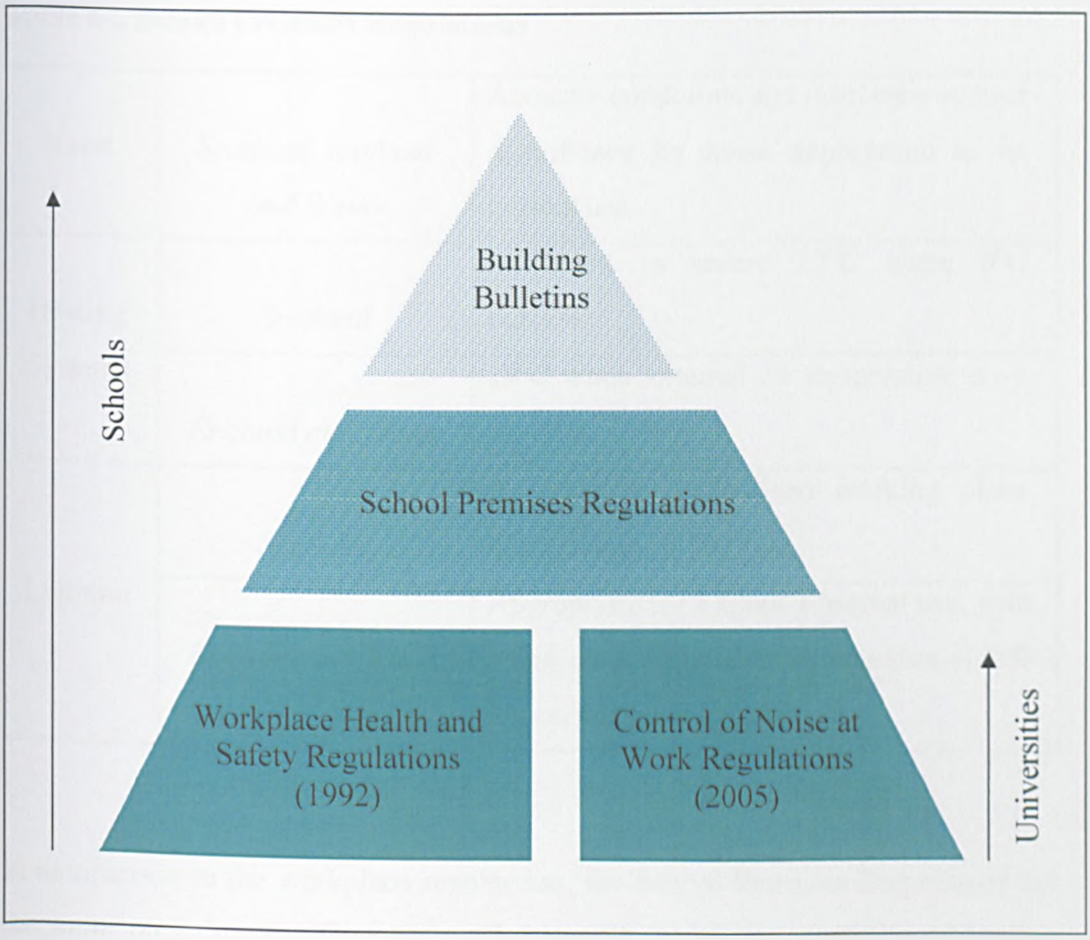


Figure 8-1 Legal requirements for environments in schools and universities

Table 8-1 Workplace Regulations

Noise	A limit of daily or weekly personal noise exposure limit value of 87 dBA, taking into account hearing protection, to which no worker should be exposed.
Temperature	During working hours the temperature in all workplaces inside buildings shall be reasonable
Lighting	Every workplace will have suitable and sufficient lighting

Schools are then subject to additional regulation. The Schools Premises Regulations begin to create a specialised school environment, setting minimum standards, with different requirements made in Scotland from England and Wales. Table 8-2 shows the parts of the Regulations that define the requirements for thermal, acoustic and lighting conditions.

Table 8-2 School Premises Regulations

Noise	*Scotland England and Wales*	Acoustic conditions and insulation against disturbance by noise appropriate to its normal use.
Heating Systems	*Scotland*	Sufficient to secure 17°C when 0°C outside.
	England and Wales	18°C when external air temperature is -1 °C
Lighting	*Scotland*	A minimum maintained working plane illumination of 108 lux.
	England and Wales	Appropriate for a space's normal use, with a minimum maintained illuminance of 300 lux on the working plane.

In comparison to the workplace regulations, the School Premises Regulations are the more prescriptive. They set a minimum limit for the capability of heating systems, and quantify standards for illuminance in classrooms. Where the Noise at Work regulations are based on minimising the risk of hearing damage, the School Premises Regulations set an expectation that classrooms should be reasonably quiet, without setting a measurable standard.

The School Premises Regulations are expanded on by the DfES Building Bulletin publications. These are the most detailed set of requirements, comprising a comprehensive range of environmental variables, using positive language to promote design excellence in schools. This makes them particularly significant to school design and operation, linking good design to the performance of the students.

The Building Bulletins state that they can be used for the design on universities. Whilst some of the requirements, such as lighting efficacy, can be considered to be universal, others are for conditions incomparable with universities. The nature of background noise will differ between schools and universities for instance, as would lighting requirements for the differing teaching styles. This limits the usefulness of the Building Bulletins for universities.

The Building Bulletins act as a comprehensive source of information for school design, in some places specifically seeking to encourage to improvements that enhance learning and concentration in the classroom. It is this combination of a detailed knowledge base in conjunction of a set of standards that is lacking for universities.

Where the same level of legislative requirement cannot be made of universities as there is with schools, there is value in adopting a comprehensive range of recommendations similar to the Building Bulletins. This would enable a cohesive approach to be taken to the design of university environments, setting a minimum standard that can be used by all involved in their design and use.

The second aim of the research was;

II. Evaluate research investigating the effects of temperature, noise and lighting on non-physical task performance individually and as interactive variables.

The review of previous literature revealed shortcomings in two main areas; the structure of research in general, and the type of methodologies traditionally employed.

Strands of environmental research have historically been categorised and separated by environmental variable. As a result, temperature, noise and lighting have been examined from different performance perspectives. Lighting studies, for instance, have been focussed on behavioural effects. Noise studies have been concerned with sustained attention and distraction in performance tests. Studies of temperature have been aimed at assessing thermal comfort, and mental performance at extreme ends of the spectrum, especially in heat.

This delineation between different aspects of the field has resulted in little cross comparison between environmental variables. Broadbent's examination of the topic in the 1960's and 1970's was the first to define theoretical interactions between stressors. There has been little further practical research examining these issues, leading to a lack of discussion and knowledge about the relative importance of each variable to task performance.

This is an important issue when considered in terms of construction costs of educational spaces. This type of knowledge could be used to direct funding towards those aspects of the built environment which most affect the performance of the occupants. The small volume of studies available which employ a multivariate structure is insufficient for such judgements of cost expenditure to be made. This acts as a barrier for the inclusion of this type of information in a specialist publication for universities, the need for which was outlined in the previous section. Presently, publications such as the Building Bulletins appear to be predominantly concerned with minimising the performance effects of noise through design and construction, disregarding any similar effects of temperature and lighting on cognition.

The nature of the variables under examination in scientific studies, such as concentration, or memory, pose unique methodological problems for the researcher. Traditional methodologies require the test subject to complete the relevant task at least twice, in order to provide a control condition as a basis for comparison. Humans are immensely sensitive to repeat testing, being vulnerable to influences such as learning effects, boredom, keenness, tiredness and competitiveness. Which effect will be predominant on a particular occasion for a given task will vary.

This is evidenced by the preliminary investigation described in Chapter 5, which is based on Pepler's seminal study of 1960. Pepler measured a 'fatigue effect', where performance deteriorates over time. The preliminary investigation instead found a statistically significant increase in speed and quality of performance over multiple testing sessions, implying some kind of motivational or learning effect. These contradictory results confirm that the human response to repeated task performance is a highly complex mechanism. This makes the separation of environmental effects from retesting effects problematic.

It is suggested that a traditional retest approach results in an over complication of the research problem. Rather than attempting to control these effects, often stronger than the effect of the environmental variable, a single-test approach can prove more suitable in some situations.

It is further suggested that studies relying on this type of methodology are measuring effects of the environmental variable on learning or demotivation, rather than assessing the core issue of the effect on performance. This is a departure from examining the response of individuals on exposure to an environment as measured in terms of performance.

Building on the results of the previous aims, the third aim of the research was;

III. Investigate the effects of temperature, noise and lighting on mood and performance through laboratory testing.

This research is the first study integrating the study of noise, temperature and lighting in the context of performance and mood of university students. The most complex interaction found was between noise, and mood. Noise was found to be a significant correlate of mood, especially associated with a decrease in Calmness. Further evidence suggested that students did not have to find a background noise distressing in order for their mood to be affected by it.

Low lighting was found to be associated with an increase in errors of concentration. Bright light, however, was found to detrimentally affect language fluency, which holds important implications for lighting design in classrooms, especially in areas which may be used for essay writing and written examinations.

Temperature was found to be the most important variable for students when assessing the comfort of their environment. Overall comfort is an important variable for the Calmness and Gregariousness mood factors, which in turn can be associated with word fluency. The 17.5°C condition was generally considered too cold by the students, which implies that the current minimum heating temperatures for schools, in the region of 17-18°C, may be inadequate.

IV. Present aspects of the classroom which could benefit most from environmental improvement.

The current minimum requirement of 17-18°C in schools was shown be too low for the thermal satisfaction of student subjects. It should be remembered that the subjects were wearing lightweight indoor clothing when making this assessment and that warmer clothing would yield different results. More importantly, results show that temperature is a prime factor in a student's assessment of the comfort provided by their environment. Whilst simply increasing the output of heating systems is the simplest way to ensure comfortable temperatures, the move towards reducing carbon emissions would prohibit this. This has implications for architects, who should actively consider controlling the thermal environment in a sustainable manner through design as well as mechanical provision. This is particularly important in lecture theatres, where students are primarily sedentary, and are therefore more likely to feel cold.

There is currently no maximum limit for working plane illuminance in schools, being based on a minimum requirement. The results have shown that bright lighting can potentially interfere with language fluency skills, and as such may prove detrimental to essay writing tasks and examinations. This has particular relevance to universities providing sports halls for examinations, where the lighting provision will generally be brighter than that found in a classroom. Universities using sports halls for examinations should consider specifying dual capability lighting schemes; a bright low-flicker provision for sporting activities; and a less harsh low-glare option for academic activities.

Background noise and acoustics is an area of the classroom where considerable thought has been applied to reducing environmental stress and problems caused by unintelligibility of speech. This has been achieved by setting maximum allowable noise levels and transmittances between walls. It is suggested that a more comprehensive approach could add further value to these standards, using both signal and physical properties of noise to reduce distraction and negative mood in the classroom. Design measures can then be taken to reduce the likelihood of particularly annoying noises transmitting to the classroom, such as siting lecture areas in quiet areas of the building or campus, or establishing 'quiet zones' in existing university buildings.

8.2 Recommendations for further research

This research has spanned a wide variety of research areas including psychology, construction standards and the fields of lighting, thermal provision and acoustics. A wide variety of suggestions for further research can be drawn from the thesis.

As a direct continuation to the study, a series of series of smaller scale 2x2 full factorial experiments would be useful in refining ideas about the interaction of the variables. The Bond Lader mood assessment has been shown to be very effective for this type of research, and future researchers should consider it for inclusion.

Results showed that word fluency performance deteriorated under the bright lighting conditions. There is scope for research further examining these effects, with a view to establishing a maximum illumination level.

There is currently discussion regarding the eventual phasing out of incandescent lightbulbs in favour of fluorescent energy saving lightbulbs. As with all fluorescent lighting, they are subject to flicker. This thesis used incandescent bulbs to control for the effects of flicker. A similar study examining the additional effects of flicker as an environmental variable would be a topical expansion to these results.

The classroom environment is peculiar in that students have very little control over their environments. Their choices are generally restricted to a small range of adaptive actions to their environment, such as removing their coat or adding a pullover. Increasing the students' control over their environment could prove beneficial, given the relationship between mood, comfort and performance. This could be readily achievable by teachers and lecturers integrating an environment check into their lecturing routine, where students can agree on any modifications required i.e. drawn curtains, post a 'silence' notice in the corridor, switch air-conditioning on or off, etc. Further research into the effectiveness of such measures would have much practical value.

References

BS EN ISO 7726:2001 Ergonomics of the thermal environment - Instruments for measuring physical quantities.

BS EN ISO 7730:2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

The Education (School Premises) Regulations 1999.

The School Premises (General Requirements and Standards) (Scotland) Regulations 1967 to 1979.

(1972). Criteria for a Recommended Standards - Occupational Exposure to Hot Environments. Cincinnati, National Institute for Occupational Safety and Health (NIOSH).

(1992). The Workplace (Health, Safety and Welfare) Regulations

(1999). Building Bulletin 90: Lighting Design for Schools. DfES, The Stationary Office.

(1999). Planning and Design Data, Architectural Press.

(2003). Building Bulletin 87: Guidlines for Environmental Design in Schools. DfES, The Stationary Office.

(2003). Building Bulletin 93: Acoustic design of schools - a design guide. DfES, The Stationary Office.

(2005). The Control of Noise at Work Regulations

(2007). School Design: Optimising the internal environment. S. Executive.

Abeywickrama, M. G. (1997). Fluorescent Lamps. Lamps and Lighting. J. R. Coaton and A. M. Marsden. London, Arnold: 194-215.

Adair, J. G. (1984). "The Hawthorne Effect: A reconsideration of the Methodological Artifact." Journal of Applied Psychology **69**(2): 334-345.

Ahearn, E. P. (1997). "The use of visual analog scales in mood disorders: A critical review." Journal of Psychiatric Research **31**(5): 569-579.

Allnutt, M. F. and J. R. Allan (1973). "The effects of core temperature elevation and thermal sensation on performance." Ergonomics **16**(2): 189-196.

ASHRAE (2005). Handbook 2005: Fundamentals, Chapter 8: Thermal Comfort.

Banbury, S. P. and D. C. Berry (2005). "Office noise and employee concentration: Identifying causes of disruption and potential improvements." Ergonomics **48**(1): 25-37.

Baron, R. A., M. S. Rea, et al. (1992). "Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: The potential mediating role of positive affect." Motivation and Emotion **16**(1): 1-33.

Bartholemew, R. (1975). "Lighting in the Classroom." Building Research and Practice **31**(1): 32-38.

Bell, C. R. and K. A. Provins (1962). "Effects of high temperature environmental conditions on human performance." Journal of Occupational Medicine **4**(4): 202-211.

Belojevic, G., V. Slepcevic, et al. (2001). "Mental performance in noise: The role of introversion." Journal of Environmental Psychology **21**: 209-213.

Bengtsson, J. (2004). "Is a "pleasant" low-frequency noise also less annoying?" Journal of Sound and Vibration **277**: 535-537.

Bengtsson, J., K. P. Waye, et al. (2004). "Evaluations of effects due to low-frequency noise in a low demanding work situation." Journal of Sound and Vibration **278**: 83-99.

Benton, S. and H. Leventhall (1986). "Experiments into the impact of low level, low frequency noise upon human behaviour." Journal of Low Frequency Noise and Vibration **5**(4): 143-162.

Bernard, T. E., F. N. Dukes-Dobos, et al. (1994). "Evaluation and control of hot working environments: Part II - The scientific basis (knowlege base) for the guide." International Journal of Industrial Ergonomics **14**: 129-138.

Boman, E. and I. Enmarker (2004). "Factors affecting pupils' noise annoyance on schools: The building and testing of models." Environment and Behavior **36**(2): 207-228.

Bommel, W. J. M. V. and G. J. V. d. Beld (2004). "Lighting for work: a review of visual and biological effects." Lighting Research and Technology **36**(4): 255-269.

Bond, A. and M. Lader (1974). "The use of analogue scales in rating subjective feelings." British Journal of Medical Psychology **47**: 211-218.

Bonnes, M. and G. Secchiaroli (1995). Environmental Psychology A Psycho-social Introduction. London, SAGE Publications.

Boray, P. F., R. Gifford, et al. (1989). "Effects of warm white, cool white and full spectrum fluorescent lighting on simple cognitive performance, mood and ratings of others." Journal of Environmental Psychology 9(4): 297-307.

Boyce, P. R. (2003). Human Factors in Lighting. London, Taylor and Francis.

Boyce, P. R., N. Eklund, et al. (2000). "Individual lighting control: Task performance, mood and illuminance." Journal of the Illuminating Engineering Society 29(1): 131-142.

Brickenkamp, R. and E. Zillmer (1998). d2 test of attention: Manual. Oxford, Hogrefe.

Broadbent, D. E. (1952). "Listening to one of two synchronous messages." Journal of Experimental Psychology 44(2): 51-55.

Broadbent, D. E. (1963). "Differences and Interactions Between Stresses." Quarterly Journal of Experimental Psychology 15(3): 205-211.

Broadbent, D. E. (1971). Decision and Stress. London, Academic Press.

Broadbent, D. E. (1978). "The current state of noise research: reply to Poulton." Psychological Bulletin 85(8): 1052-1067.

Bronzaft, A. L. and K. P. McCarthy (1975). "The effect of elevated train noise on reading ability." Environment and Behavior 7(4): 517-527.

Butera, F. M. (1998). "Chapter 3 - Principles of thermal comfort." Renewable and sustainable energy review 2: 39-66.

Chiles, W. D. (1958). "Effects of elevated temperatures on performance of a complex mental task." Ergonomics 2: 89-96.

CIBSE (1991). Lighting Guide 5: The Visual Environment in Lecture, Teaching and Conference Rooms, CIBSE.

CIBSE (2002). Code for lighting. Oxford, Butterworth Heinemann.

Clark, R. P. and O. G. Edholm (1985). Man and his Thermal Environment. London, Edward Arnold.

Clarke, G. M. and D. Cooke (2004). A basic course in statistics. London, OUP.

Clausen, G., L. Carrick, et al. (1993). "A comparative study of discomfort caused by indoor air pollution, thermal load and noise." Indoor Air 3: 255-262.

Cohen, S. (1981). "Nonauditory effects of noise on behavior and health." Journal of Social Issues 37(1): 36-70.

Cole, G. A. (2000). Management Theory and Practice. London, Continuum.

Conrad, D. W. (1973). "The effects of intermittent noise on human serial decoding performance and physiological response." Ergonomics **16**(6): 739-747.

Costello, A. B. and J. W. Osborne (2005). "Best practices in exploratory factor analysis: Four recommendations for getting the best from your analysis." Practical assessment research and evaluation **10**(7): 1-9.

Countryman, C. C. and S. Jang (2006). "The effects of atmospheric elements on customer impression: the case of hotel lobbies " International Journal of Contemporary Hospitality Management **18**(7): 534-545.

Daanen, H. A. M., E. v. d. Vliert, et al. (2003). "Driving performance in cold, warm and thermoneutral environments." Applied Ergonomics **34**: 597-602.

Diaper, G. (1990). "The Hawthorne Effect: A fresh examination." Educational Studies **16**(3): 261-267.

Enander, A. (1987). "Effects of moderate cold on performance of psychomotor and cognitive tasks." Ergonomics **30**(10): 1431-1445.

Evans, G. W. and S. J. Lepore (1993). "Nonauditory effects of noise on children: A critical review." Children's Environments **10**(1): 31-51.

Evans, G. W. and L. Maxwell (1997). "Chronic noise exposure and reading deficits: The mediating effects of language acquisition." Environment and Behavior **29**(5): 638-656.

Everest, F. A. (1994). The master handbook of acoustics. New York, McGraw Hill.

Folstein, M. F. and R. Luria (1973). "Reliability, validity, and clinical application of the visual analogue mood scale." Psychological Medicine **3**: 479-486.

Forster, R. (1997). Interior Lighting. Lamps and Lighting. J. R. Coaton and A. M. Marsden. London, Arnold: 400-444.

Fostervold, K. I., E. Buckmann, et al. (2001). "VDU-screen filters:remedy or the ubiquitous Hawthorne effect?" International Journal of Industrial Ergonomics **27**(2): 107-118.

Freyd, M. (1923). "The graphic rating scale." Journal of Educational Psychology **14**: 83-102.

Furnham, A. and L. Strbac (2002). "Music is as distracting as noise: the differential distraction of background music and noise on the cognitive test performance of introverts and extraverts." Ergonomics **45**(3): 203-217.

Gawron, V. J. (1984). "Noise: effect and aftereffect." Ergonomics **27**(1): 5-18.

Givoni, B. and Y. Rim (1964). "Effect of the thermal environment and psychological factors upon subjects' reponses and performance of mental work." Ergonomics **5**: 99-114.

Grether, W., C. Harris, et al. (1971). "Effects of combined heat, noise and vibration stress on human performance and physiological functions." Aerospace Medicine **42**(10): 1092-1097.

Grether, W., C. Harris, et al. (1972). "Further study of combined heat, noise and vibration stress." Aerospace Medicine **43**(6): 641-645.

Griffiths, I. D. and P. R. Boyce (1971). "Performance and thermal comfort." Ergonomics **14**(4): 457-468.

Halstead, M. B. (1997). Colour. Lamps and Lighting. J. R. Coaton and A. M. Marsden. London, Arnold: 46-69.

Hancock, P. (1986). "Sustained attention under thermal stress." Psychological Bulletin **99**(2): 263-281.

Hancock, P. A. and J. O. Pierce (1985). "Combined effects of heat and noise on human performance: A review." American Industrial Hygiene Association Journal **46**(10): 555-566.

Hancock, P. A. and I. Vasmatzidis (1998). "Human Occupational and performance limits under stress: the thermal environment as a prototypical example." Ergonomics **41**(8): 1169-1191.

Hansson, M. and R. Wigblad (2006). "Recontextualising the Hawthorne effect." Scandanavian Journal of Management **22**(2): 120-137.

Haslam, R. A. and K. C. Parsons (1987). "A comparison of methods for predicting human response to hot and cold environments." Ergonomics **30(11)**: **1599-1614**.

Hathaway, W. E. (1995). "Effects of school lighting on physical development and school performance." The Journal of Educational Research **88**(4): 228-242.

Hayes, M. H. S. and D. G. Patterson (1921). "Experimental development of the graphic rating method." Psychological Bulletin **18**: 98-99.

Heschong, L., R. L. Wright, et al. (2002). "Daylighting Impacts on Human Performance in School." Journal Of The Illuminating Engineering Society.

Hinton, P. R., C. Brownlow, et al. (2004). SPSS Explained, Routledge.

Holmér, I. (1994a). "Cold stress: Part I - Guidelines for the practitioner." International Journal of Industrial Ergonomics **14**: 139-149.

Holmér, I. (1994b). "Cold stress: Part II - The scientific basis (knowledge base) for the guide." International Journal of Industrial Ergonomics **14**: 151-159.

Howe, S. H. and I. Connor (1997). Incandescent Lamps. Lamps and Lighting. J. R. Coaton and A. M. Marsden. London, Arnold: 161-176.

Hygge, S. (1991). "The interaction of noise and mild heat on cognitive performance and serial reaction time." Environment International **17**: 229-234.

Hygge, S., E. Boman, et al. (2003). "The effects of road traffic noise and meaningful irrelevant speech on different memory systems." Scandanavian Journal of Psychology **44**(1): 13-21.

Hygge, S. and I. Knez (2001). "Effects of noise, heat and indoor lighting on cognitive performance and self-reported affect." Journal of Environmental Psychology **21**: 291-299.

Karjalainen, S. (2007). "Gender differences in thermal comfort and use of thermostats in everyday thermal environments." Building and Environment **42**: 1594-1603.

Kennedy, D. O., A. B. Scholey, et al. (2002). "Modulation of cognition and mood following administration of single doses of Ginko biloba, ginseng, and a ginko/ginseng combination to healthy adults." Physiology and Behavior **75**: 739-751.

Kjellberg, A. and O. Landström (1994). "Noise in the office: Part II - The scientific basis (knowledge base) for the guide." International Journal of Industrial Ergonomics **14**: 93-118.

Kjellberg, A., U. Landström, et al. (1996). "The effects of nonphysical noise characteristics, ongoing task and noise sensitivity on annoyance and distraction due to noise at work." Journal of Environmental Psychology **16**: 123-136.

Kjellberg, A., P. Muhr, et al. (1998). "Fatigue after work in noise - an epidemiological survey study and three quasi-experimental field studies." Noise and health **1**: 47-55.

Knez, I. (1995). "Effects of indoor lighting on mood and cognition." Journal of Environmental Psychology **15**(1): 39-51.

Knez, I. (2001). "Effects of colour of light on nonvisual psychological processes." Journal of Environmental Psychology **21**: 201-208.

Knez, I. and I. Enmarker (1998). "Effects of office lighting on mood and cognitive performance and a gender effect in work-related judgement." Environment and Behavior **30**(4): 553-567.

Knez, I. and C. Kers (2000). "Effects of indoor lighting, gender, and age on mood and cognitive performance." Environment and Behavior **32**(6): 817-831.

Kreindler, D., A. Levitt, et al. (2003). "Portable mood mapping: the validity and reliability of analog scale displays for mood assessment via hand-held computer." Psychiatry Research **120**: 165-177.

Krüger, E. l. and P. H. T. Zannin (2004). "Acoustic, thermal and luminous comfort in classrooms." Building and Environment **39**: 1055-1063.

Kryter, K. D. (1994). The Handbook of Hearing and the Effects of Noise. San Diego, CA, Academic Press.

Küller, R. and T. Laike (1998). "The impact of flicker from fluorescent lighting on well-being, performance and physiological arousal." Ergonomics **41**(4): 433-447.

Küller, R. and C. Lindsten (1992). "Health and behavior of children in classrooms with and without windows." Journal of Environmental Psychology **12**: 305-317.

La Gennusa, M., Antonio Nucara, Gianfranco Rizzo, Gianluca Scaccianoce (2005). "The calculation of the mean radiant temperature of a subject exposed to the solar radiation - a generalised algorithm." Building and Environment **40**: 367-375.

Leonard, K. and M. C. Masatu (2006). "Outpatient process quality evaluation and the Hawthorne Effect." Social Science and Medicine **63**(9): 2330-2340.

Lercher, P., G. W. Evans, et al. (2003). "Ambient noise and cognitive processes among primary schoolchildren." Environment and Behavior **35**(6): 725-735.

Likert, R. (1932). "A technique for the measurement of attitudes." Archives of psychology **22**: 5-54.

Luria, R. E. (1975). "The validity and reliability of the visual analogue mood scale." Journal of Psychiatric Research **12**: 51-57.

Mackworth, N. (1950). Researches on the measurement of human performance. London, HMSO.

MacPherson, R. K. (1973). "Thermal stress and thermal comfort." Ergonomics **16**(5): 611-623.

Maxwell, L. A. and G. W. Evans (2000). "The effects of noise on pre-school children's pre-reading skills." Journal of Environmental Psychology **20**: 91-97.

Mehrabian, A. and J. A. Russell (1974). An approach to environmental psychology. Cambridge, MIT Press.

Melamed, S. and S. Bruhis (1996). "The effects of chronic industrial noise exposure on urinary cortisol, fatigue and irritability." JOEM **38**(3): 252-256.

Morris, L. A. (1995). "Practical issues in the measurement of heat stress." Ergonomics **38**(1): 183-192.

Müller, B. H. and T. Hettinger (1995). "Influence and assessment of heat radiation." Ergonomics **38**(1): 128-137.

Nelson, T. M., T. H. Nilsson, et al. (1984). "Interaction of temperature, illuminance and apparant time on sedentary work fatigue." Ergonomics **27**(1): 89-101.

ODPM (2000). The Building Regulations Part E: Resistance to the passage of sound.

Oleson, B. W. (1995). "Measurement of the physical parameters of the environment." Ergonomics **38**(1): 138-153.

Oseland, N. A. H., M A (1994). Trends in thermal comfort research, Building Research Establishment.

OSRAM (2000). Technical Information Bulletin: Spectral Power Distributions of SYLVANIA Fluorescent Lamps. US, OSRAM Sylvania.

Owen, F. and R. Jones (1993). Statistics. London, Pitman.

Parsons, K. C. (1995). "International heat stress standards: a review." Ergonomics **38**(1): 6-22.

Pepler, R. D. (1958). "Warmth and performance: An investigation in the tropics." Ergonomics **2**(1): 63-88.

Pepler, R. D. (1960). "Warmth, glare and a background of quiet speech: A comparison of their effects on performance." Ergonomics **3**: 68-73.

Pilcher, J. J., E. Nadler, et al. (2002). "Effects of hot and cold temperature exposure on performance: a meta-analytic review." Ergonomics **45**(10): 682-698.

Provins, K. A., D. J. Glencross, et al. (1973). "Thermal stress and arousal." Ergonomics **16**(5): 623-631.

Raffaello, M. and A. Maass (2002). "Chronic exposure to noise in industry: The effects on satisfaction stress symptoms and company attachment." Environment and Behavior **34**(5): 651-671.

Ramsey, J. D. (1995). "Task performance in heat: A review." Ergonomics **38**(1): 154-165.

Ramsey, J. D., T. E. Bernard, et al. (1994). "Evaluation and control of hot working environments: Part I - Guidelines for the practitioner." International Journal of Industrial Ergonomics **14**: 119-127.

Ramsey, J. D. and Y. G. Kwon (1992). "Recommended alert limits for perceptual motor loss in hot environments." International Journal of Industrial Ergonomics **9**: 245-257.

Rees, D. G. (1995). Essential Statistics. London, Chapman and Hall.

Rooney, J. (1994). "Ergonomics in academic libraries." Library Management **15**(1): 26-35.

Ruff, R. (1997). "The psychological construct of word fluency." Brain and Language **57**: 394-405.

Schweizer, K. and H. Moosbrugger (2004). "Attention and working memory as predictors of intelligence." Intelligence **32**: 329-347.

Schweizer, K., H. Moosbrugger, et al. (2005). "The structure of the relationship between attention and intelligence." Intelligence **33**(6): 589-611.

Sharma, A. and T. F. Stafford (2000). "The effect of retail atmospherics on customers' perceptions of salespeople and customer persuasion." Journal of Business Research **49**(2): 183-191.

Shield, B. M. and J. E. Drockrell (2003). "The effects of noise on children at school: A review." Buildings Acoustics **10**(2): 97-116.

Shoemaker, J. A. and R. Refinetti (1996). "Day-night difference in the preferred ambient temperature of human subjects." Physiology and Behavior **59**(4/5): 1001-1003.

Smith, A. P. and D. E. Broadbent (1980). "Effects of noise on performance on embedded figures task." Journal of Applied Psychology **65**(2): 246-248.

Smith, B. J., R. J. Peters, et al. (1996). Acoustics and noise control, Longman.

Smith, R. and G. Bradley (1994). "The influence of thermal conditions on teachers work and student performance." Journal of Educational Administration **32**(1): 34-42.

Speakman, J. R. (2004). "Thermoregulation." Encyclopedia of Energy **6**: 125-137.

Streiner, D. L. and G. R. Norman (2005). Health measurement scales: A practical guide to their development and use. Oxford, Oxford University Press.

Summers, T. A. and P. R. Hebert (2001). "Shedding some light on store atmospherics: Influence of illumination on consumer behaviour." Journal of Business Research **54**(2): 145-150.

Tecce, J. J. (1998). "Theories of arousal: Then and now." International Journal of Psychophysiology **30**(1-2): 9.

Toftum, J. (2002). "Human response to combined indoor environmental exposures." Energy and Buildings **34**: 601-606.

Trimmel, M. and G. Poelzl (2006). "Impact of background noise on reaction time and brain DC potential changes of VDT-based spatial attention." Ergonomics **49**(2): 202-208.

Tseng, H.-M., H. A. Macleod, et al. (1997). "Computer anxiety and measurement of mood change." Computers in human behaviour **13**(3): 305-316.

Vasmatzidis, I., R. E. Schlegel, et al. (2002). "An investigation of heat stress effects on time-sharing performance." Ergonomics **45**(3): 218-239.

Veitch, J. A. (1996). "Choice, perceived control, and performance decrements in the physical environment." Journal of Environmental Psychology **16**: 269-276.

Veitch, J. A. (1997). "Revisiting the performance and mood effects of information about lighting and fluorescent lamp type." Journal of Environmental Psychology **17**(3): 253-262.

Veitch, J. A., R. Gifford, et al. (1991). "Demand characteristics and full spectrum lighting effects on performance and mood." Journal of Environmental Psychology **11**(1): 87-95.

Veitch, J. A. and S. L. McColl (2001). "A critical examination of perceptual and cognitive effects attributed to full-spectrum fluorescent lighting." Ergonomics **44**(3): 255-279.

Watson, D. and L. A. Clark (1988). "Development and validation of brief measures of positive and negative affect: The PANAS scales." Journal of Personality and Social Psychology **54**(6): 1063-1070.

Waye, K. P., R. Ryelander, et al. (1997). "Effects on performance and work quality due to low frequency ventilation noise." Journal of Sound and Vibration **205**(4): 467-474.

Webb, A. R. (2006). "Considerations for lighting in the built environment: Non-visual effects of light." Energy and Buildings **38**(7): 721-727.

Weinstein, N. D. (1974). "Effect of noise on intellectual performance." Journal of Applied Psychology **59**(5): 548-554.

Wharmby, D. O. (1997). Radiation and Light Production. Lamps and Lighting. J. R. Coaton and A. M. Marsden. London, Arnold: 95-118.

Wigö, H. and I. Knez (2005). "Psychological impact of air velocity variations in a ventilated room." Ergonomics **48**(9): 1086-1096.

Wilkins, A. J., I. Nommo-Smith, et al. (1989). "Fluorescent lighting, headaches and eyestrain." Lighting Research and Technology **21**(1): 11-18.

Wiltshire, L. C. (1997). Light. Lamps and Lighting. J. R. Coaton and A. M. Marsden. London, Arnold: 3-22.

Zealley, A. and R. Aitken (1969). "Measurement of mood." Proceedings of the Royal Society of Medicine **62**: 993-996.

Zuckerman, M. and B. Lubin (1965). Manual for the multiple affect adjective checklist, EdITS

Appendices

Appendix 6 A Differences between interpolated performance and measured speed of performance (CP)

CP for Lighting group

	Difference in Dim Condition (CP %)	Difference in Bright Condition (CP %)
Person A	8.14	5.73
Person B	-5.34	-2.51
Person C	-16.08	-3.85
Person D	-4.59	1.09
Person E	6.67	2.01
Person F	-1.11	-1.09

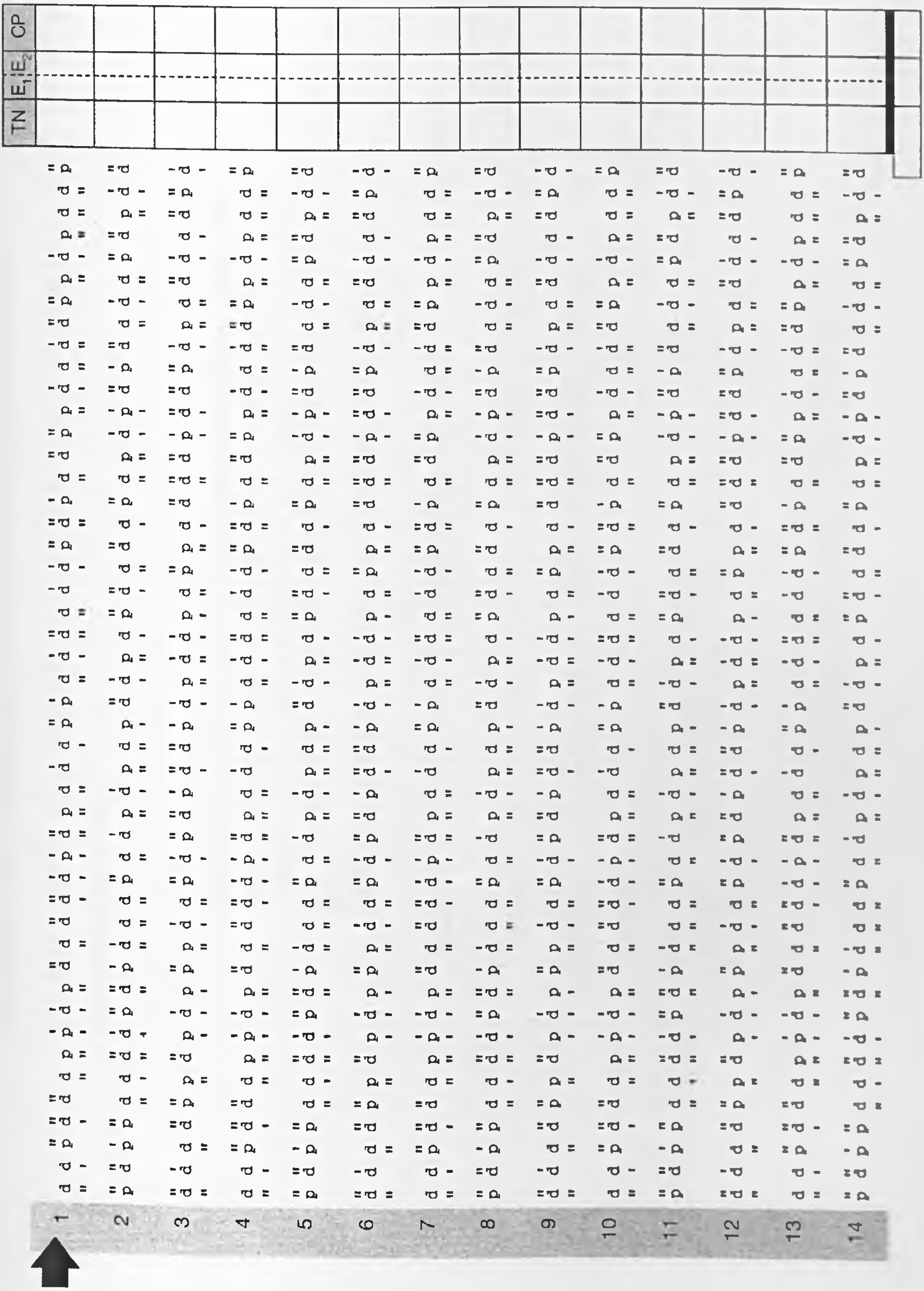
CP for Noise group

	Difference in Noisy Condition (CP %)	Difference in Quiet Condition (CP %)
Person G	-0.51	10.25
Person H	3.06	-4.62
Person I	-9.08	-14.56
Person J	1.18	-2.06
Person K	8.97	-1.06
Person L	0.88	-1.40

CP for Temperature group

	Difference in Cool Condition (CP %)	Difference in Warm Condition (CP %)
Person M	4.07	-0.36
Person N	11.89	1.98
Person O	1.18	-0.38
Person P	-0.47	-0.52

Appendix 6 A The d2 Test of attention



Appendix 6 B Bond Lader scales, Environmental VAS and additional scales

The Bond Lader test was presented during testing sessions using a portrait format, fitting on one page. A subsequent page detailed the EVAS.

- Based on how you are feeling **at the present moment**, please rate the way that you feel in terms of the dimensions given below.
- Regard each line as representing the full range of each dimension (i.e. the most alert I have ever been, the drowsiest I have ever been).
- Please mark clearly by placing a line vertically over the line.

ALERT	________________________________	DROWSY
CALM	________________________________	EXCITED
STRONG	________________________________	FEEBLE
MUZZY	________________________________	CLEAR HEADED
WELL COORDINATED	________________________________	CLUMSY

LETHARGIC ______

CONTENTED ______

TROUBLED ______

MENTALLY SLOW ______

TENSE ______

ATTENTIVE ______

INCOMPETENT ______

HAPPY ______

ANTAGONISTIC ______

INTERESTED ______

WITHDRAWN ______

HUNGRY ______

ENERGETIC

DISCONTENTED

TRANQUIL

QUICK WITTED

RELAXED

DREAMY

PROFICIENT

SAD

FRIENDLY

BORED

SOCIABLE

FULL

Overall, how would you rate your mood at the moment?

BEST EVER	________________________________	WORST EVER

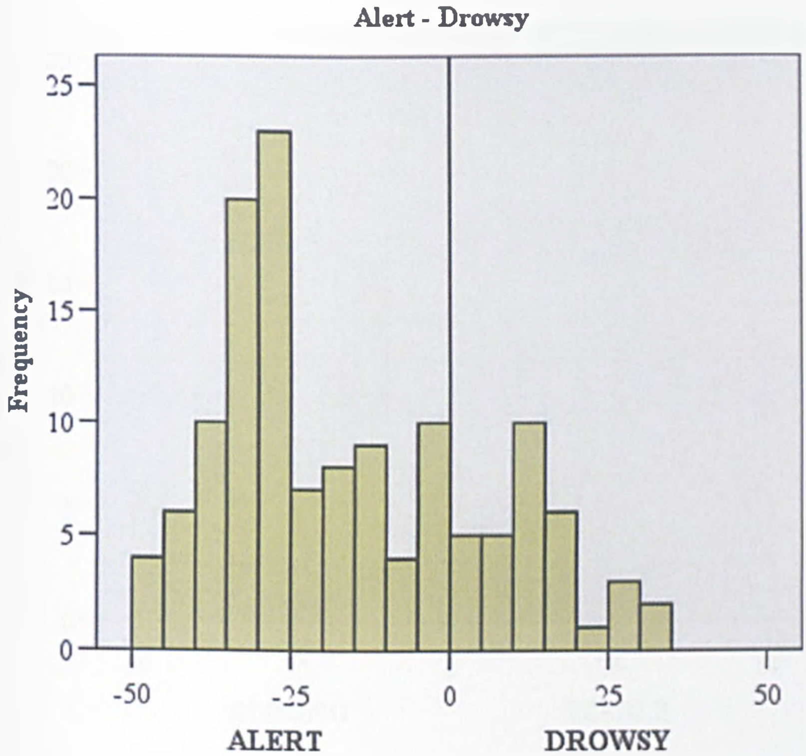
- Based on the environmental conditions that you are experiencing at the moment, please rate the way that you feel in terms of the dimensions given below.
- Regard each line as representing the full range of each dimension.
- Please mark clearly by placing a line vertically over the line.

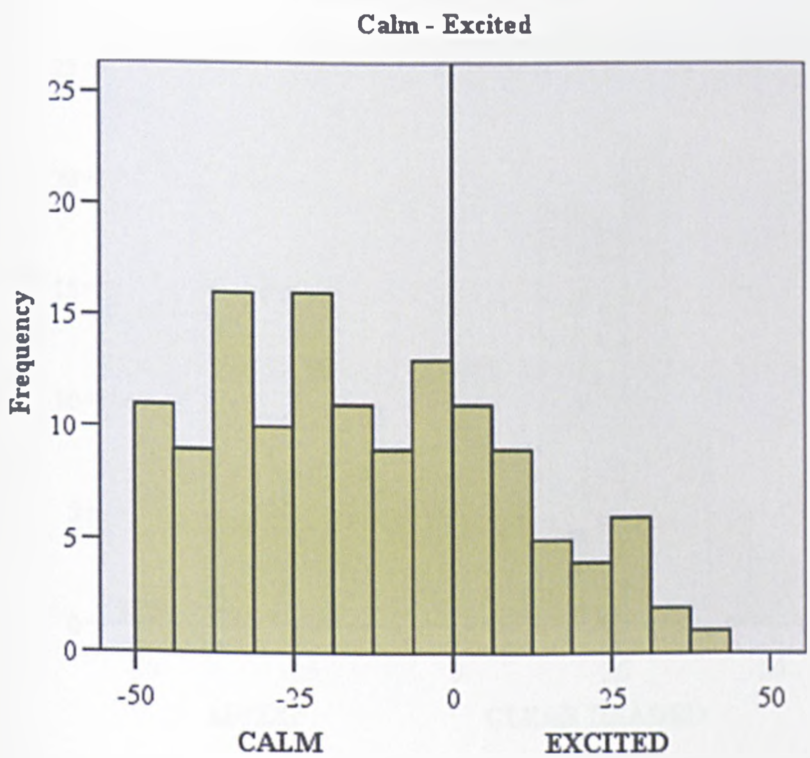
TOO HOT	________________________________	TOO COLD
TOO BRIGHT	________________________________	TOO DARK
TOO NOISY	________________________________	TOO QUIET

How comfortable do you find the room that you are in?

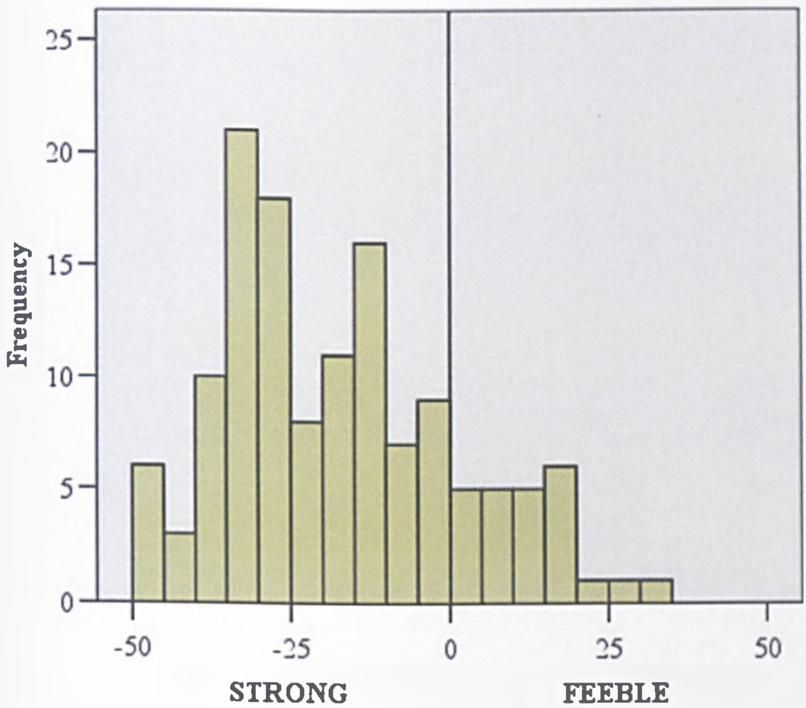
BEST EVER	________________________________	WORST EVER

Appendix 7 A Frequency distributions of Bond Lader scales

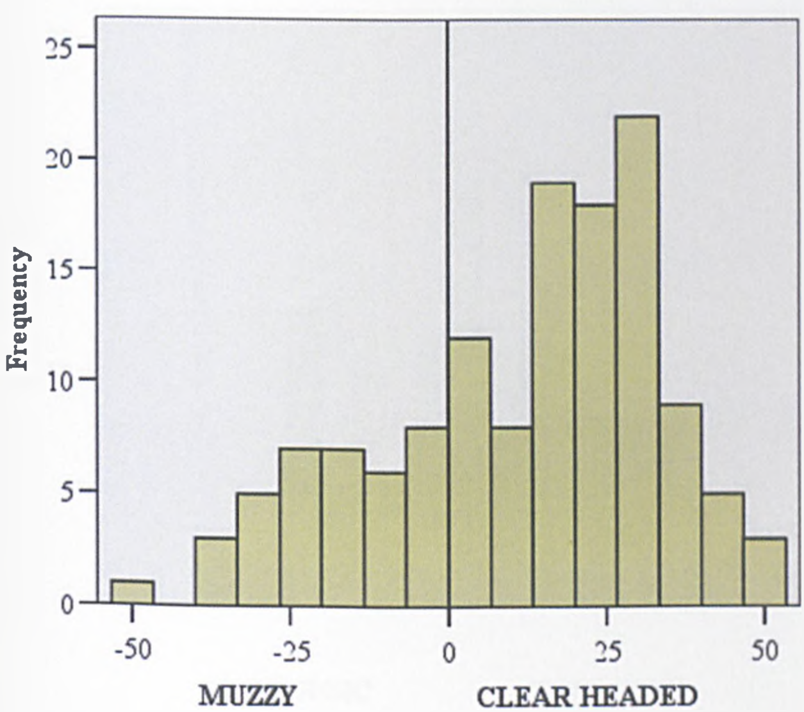




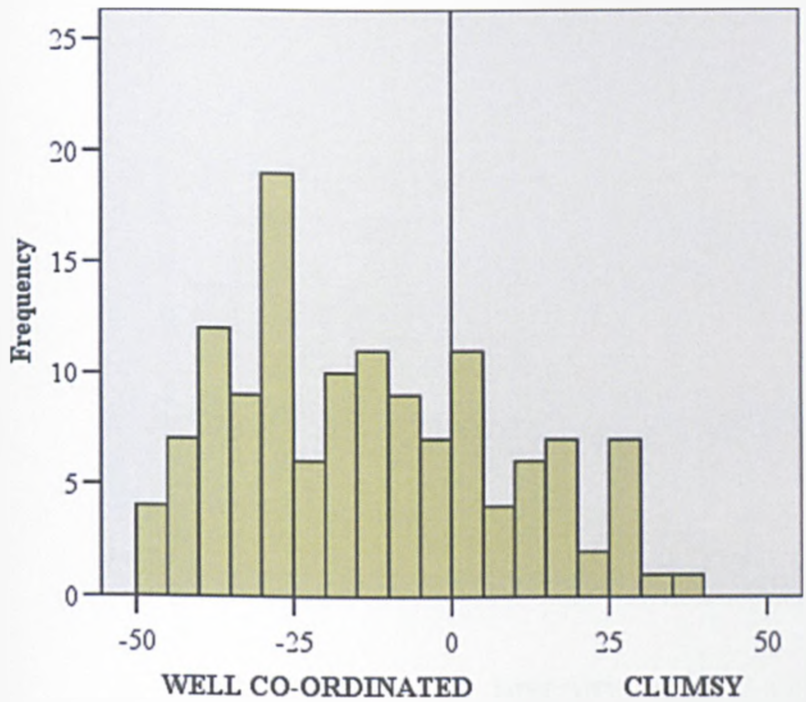
Strong - Feeble



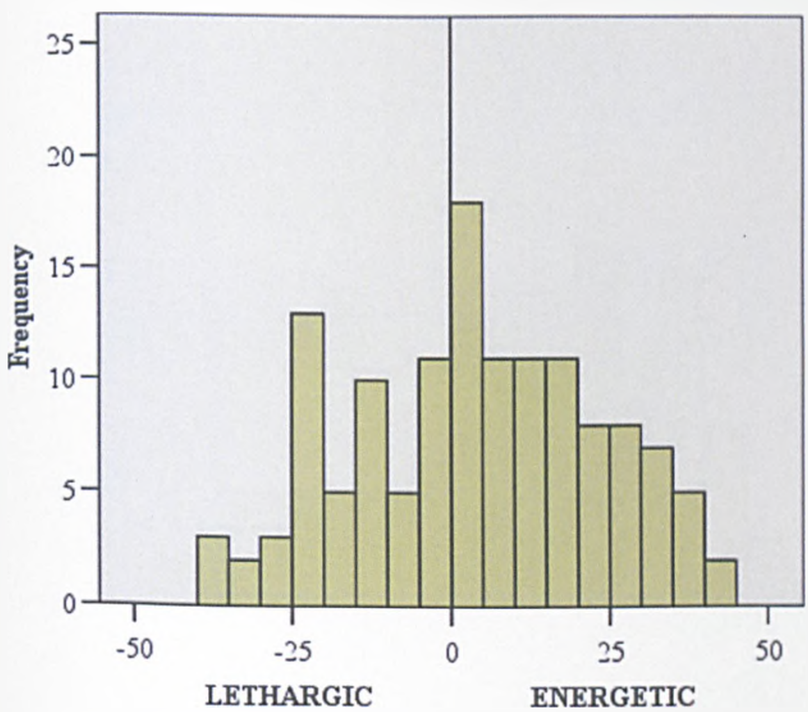
Muzzy - Clear headed



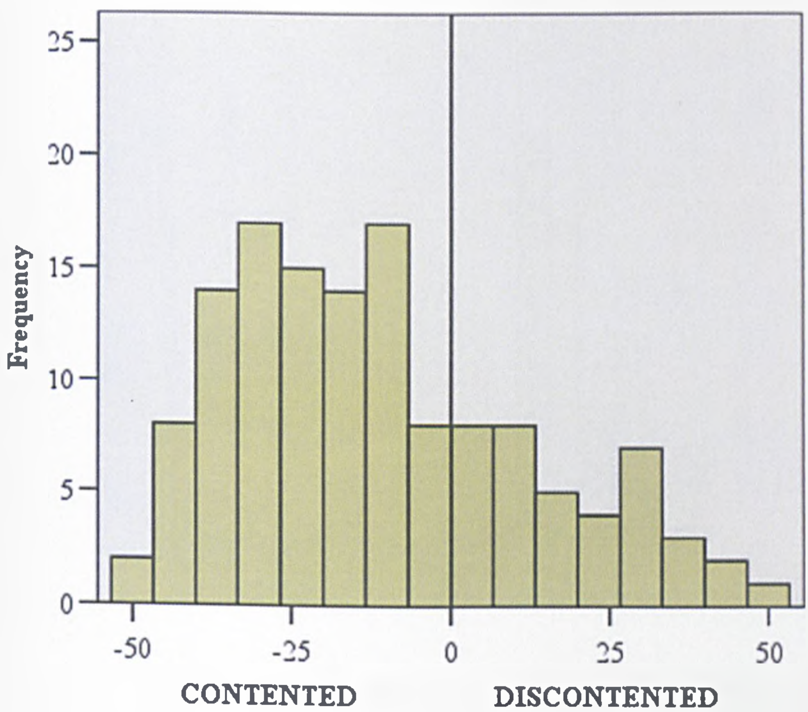
Well Co-Ordinated - Clumsy



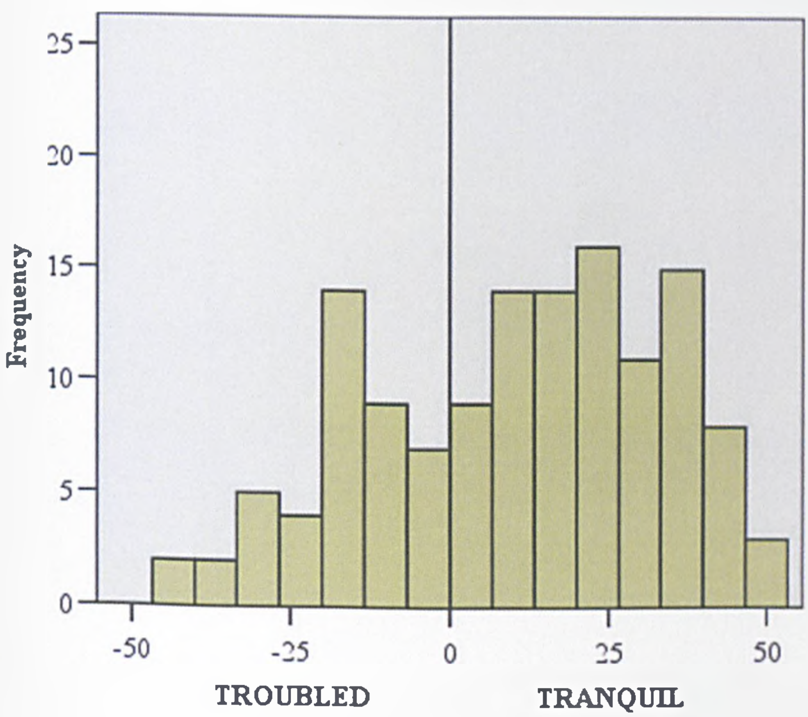
Lethargic - Energetic



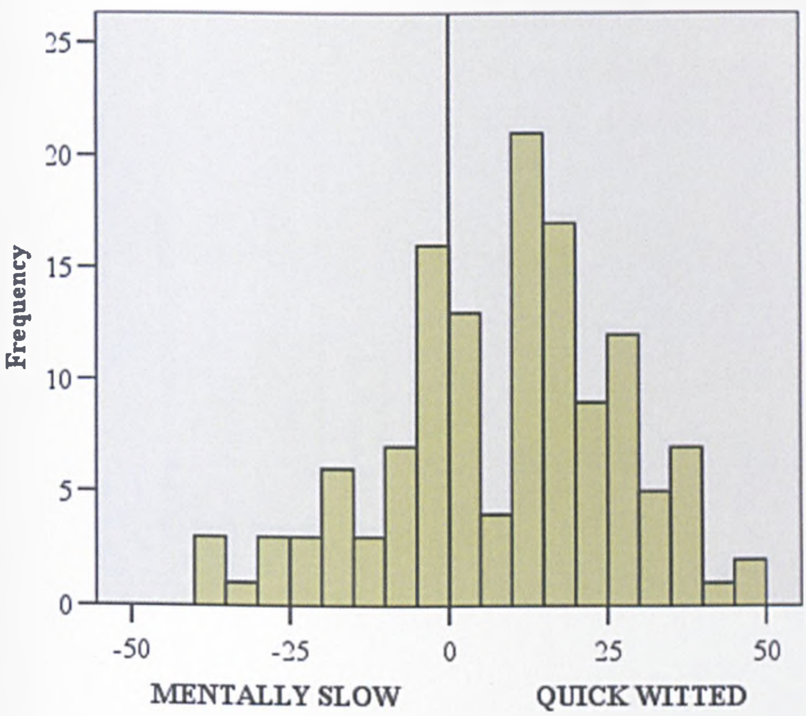
Contented - Discontented



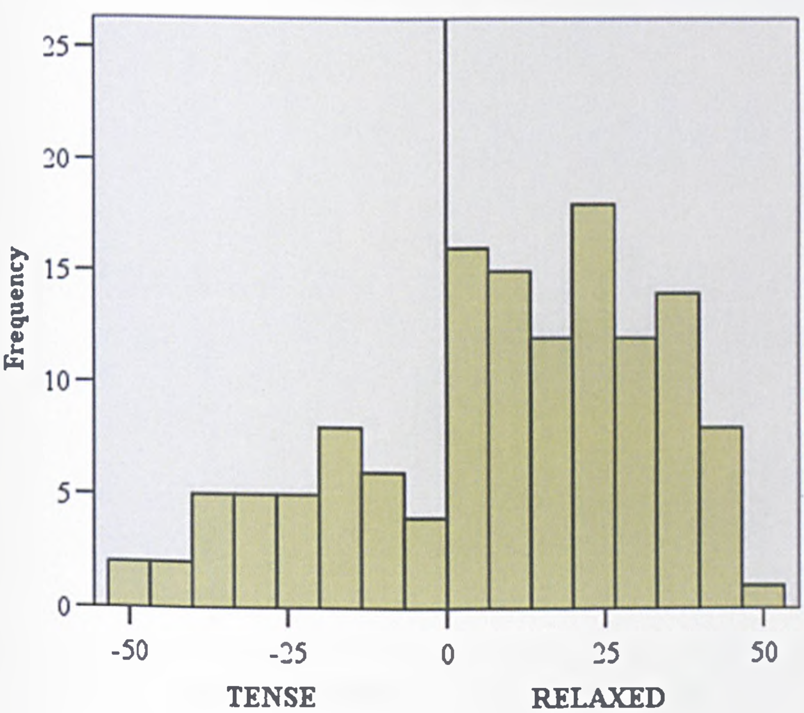
Troubled - Tranquil



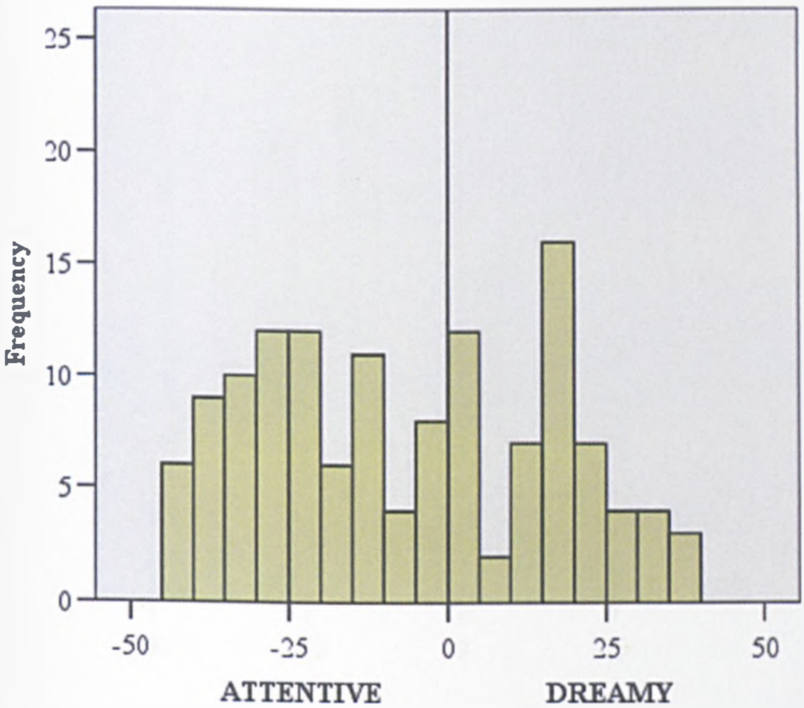
Mentally Slow - Quick Witted



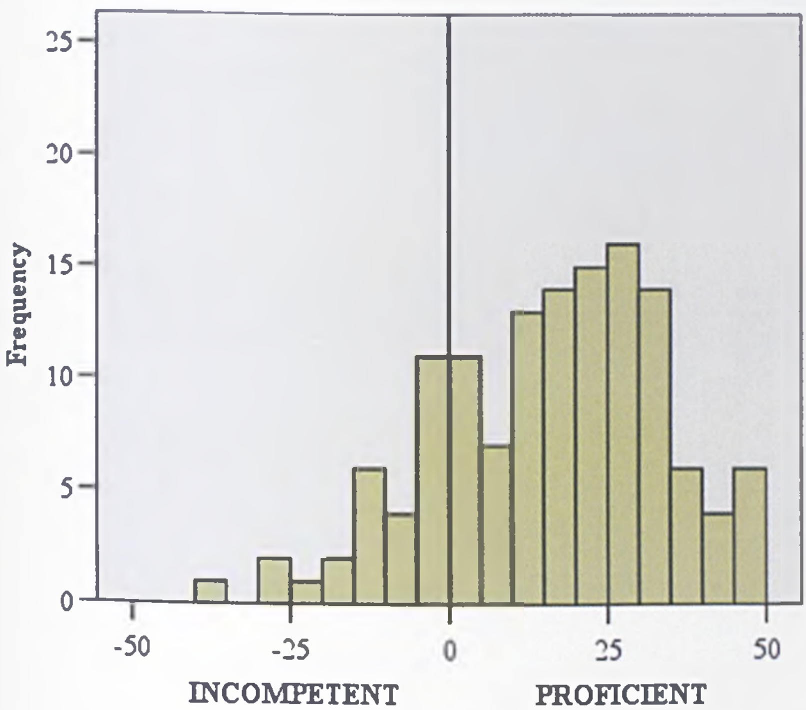
Tense - Relaxed



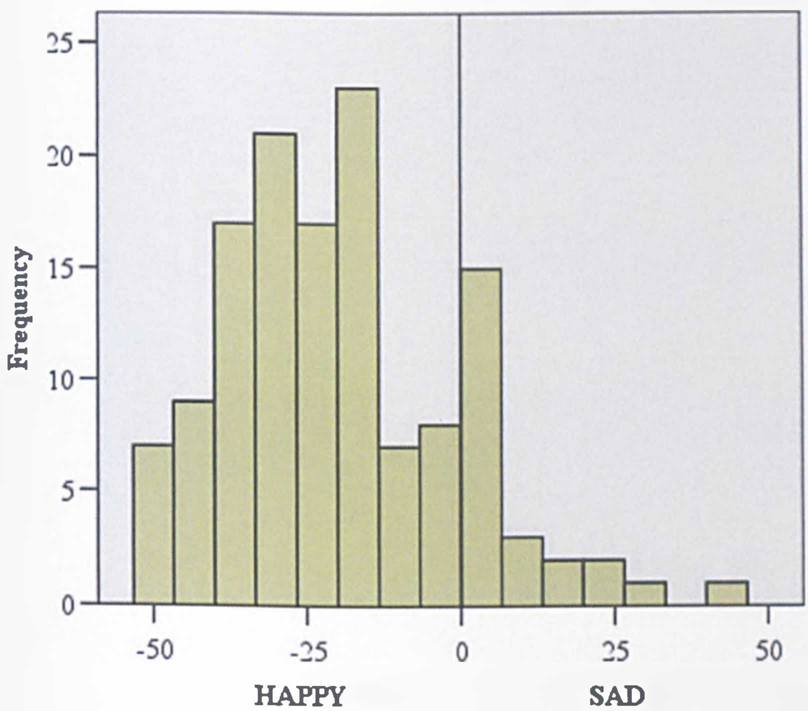
Attentive - Dreamy



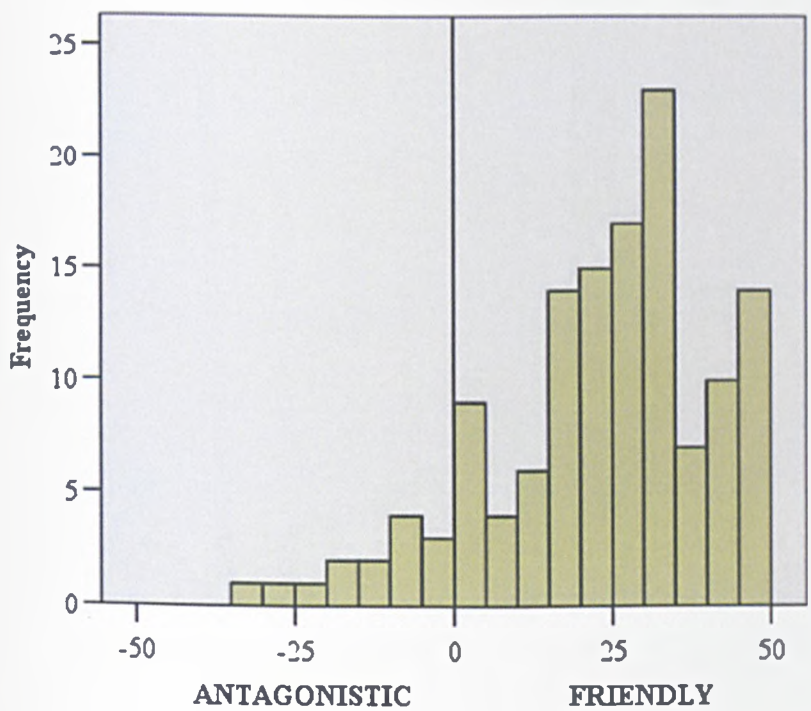
Incompetent - Proficient



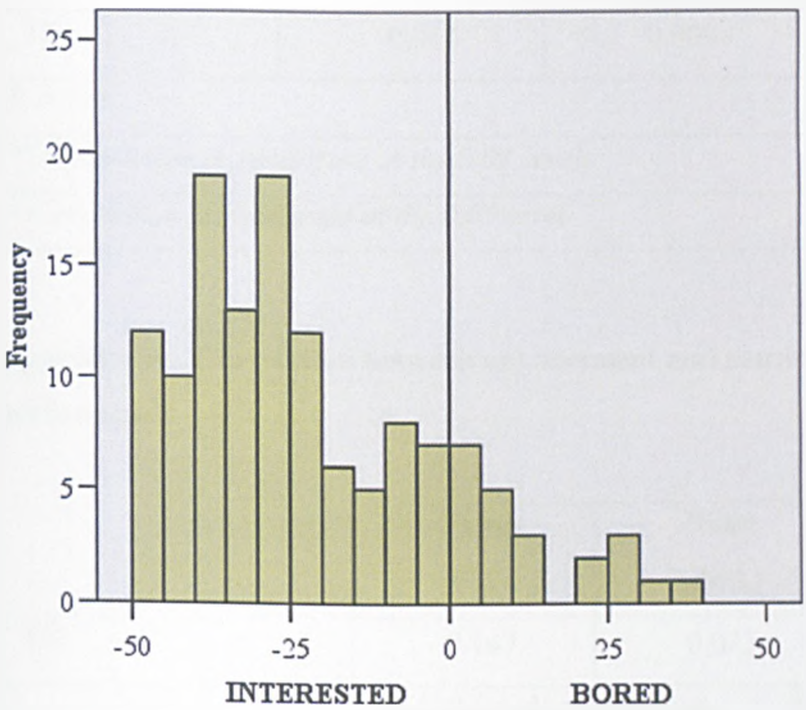
Happy - Sad



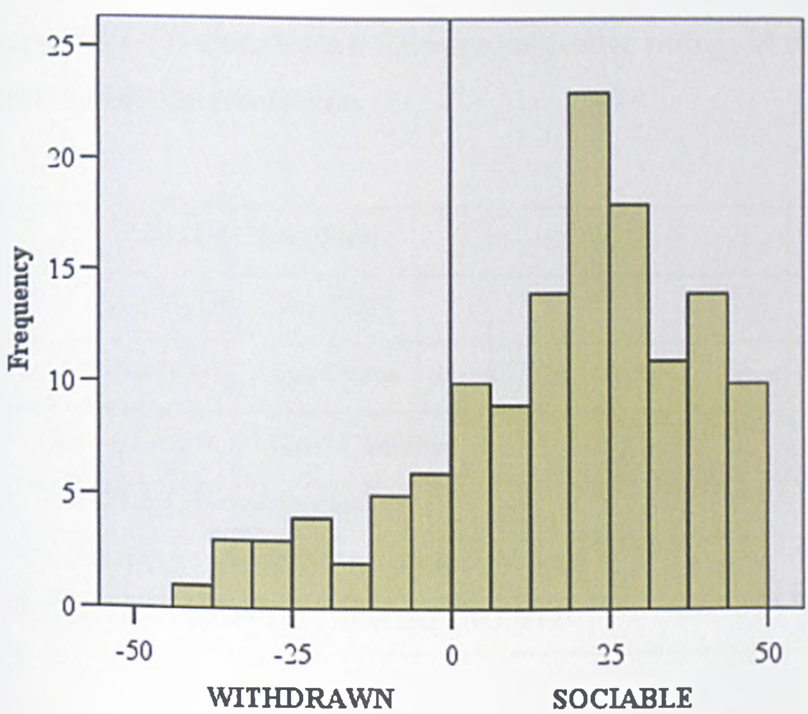
Antagonistic - Friendly



Interested - Bored



Withdrawn - Sociable



Appendix 7 B Correlations between environment and speed of performance

		Temperature (°C)	Noise (dBA)	Light (Lux)
TN	r_s	-0.015	0.009	-0.060
N = 129				
*** Correlation is significant at the 0.01 level*				
** Correlation is significant at the 0.05 level*				

Appendix 7 C Correlation between environment and consistency of performance

		Temp (°C)	Noise (dBA)	Light (Lux)
FR	r_s	0.147	0.023	0.052
N=129 for all correlations				
*** Correlation is significant at the 0.01 level*				
** Correlation is significant at the 0.05 level*				

Appendix 7 D Correlations between subjective ratings of the environment and speed of performance

		TN
Too Hot - Too Cold	r_s	0.009
Too Bright - Too Dark	r_s	-0.040
Too Noisy - Too Quiet	r_s	-0.075
Best Comfort - Worst Comfort	r_s	-0.014
N=129 for all correlations		
*** Correlation is significant at the 0.01 level*		
** Correlation is significant at the 0.05 level*		

Appendix 7 E Correlations between subjective ratings of the environment and errors

		E1	E2	E
Too Hot - Too Cold	r_s	0.033	-0.004	0.011
Too Bright - Too Dark	r_s	0.158	0.098	0.158
Too Noisy - Too Quiet	r_s	0.100	-0.077	0.092
Best Comfort - Worst Comfort	r_s	0.027	0.159	0.046
N=129 for all correlations				
*** Correlation is significant at the 0.01 level*				
** Correlation is significant at the 0.05 level*				

Appendix 7 F Correlations between subjective ratings of the environment and consistency of performance

		FR
Too Hot - Too Cold	r_s	-0.149
Too Bright - Too Dark	r_s	-0.060
Too Noisy - Too Quiet	r_s	0.015
Best Comfort - Worst Comfort	r_s	-0.007
N=129 for all correlations		
*** Correlation is significant at the 0.01 level*		
** Correlation is significant at the 0.05 level*		

Appendix 7 G Correlations between Bond Lader assessment and speed of performance

		TN
Alert – Drowsy	r_s	0.134
Energetic – Lethargic	r_s	0.050
Clearheaded – Muzzy	r_s	-0.021
Well Co-ordinated - Clumsy	r_s	0.008
Strong – Feeble	r_s	0.051
Attentive - Dreamy	r_s	-0.047
Quick Witted – Mentally Slow	r_s	0.006
Proficient - Incompetent	r_s	-0.012
Interested - Bored	r_s	0.053
Sociable - Withdrawn	r_s	-0.024
Friendly - Antagonistic	r_s	0.047
Happy - Sad	r_s	0.031
Calm – Excited	r_s	-0.007
Tranquil - Troubled	r_s	0.103
Contented - Discontented	r_s	0.017
Relaxed - Tense	r_s	0.049
N=129 for all correlations		
*** Correlation is significant at the 0.01 level*		
** Correlation is significant at the 0.05 level*		

Appendix 7 H Correlations between speed of performance and overall mood and hunger

		TN
Hungry - Full	r_s	0.058
Best Mood –Worst Mood	r_s	-0.167
N=129 for all correlations		
*** Correlation is significant at the 0.01 level*		
** Correlation is significant at the 0.05 level*		

Appendix 7 I Correlations (r_s) between Bond Lader assessment and Errors (non significant)

		E1	E2	E
Alert – Drowsy	r_s	0.097	-0.042	0.087
Energetic – Lethargic	r_s	0.111	-0.059	0.094
Clearheaded – Muzzy	r_s	0.012	0.055	0.026
Well Co-ordinated - Clumsy	r_s	0.116	-0.124	0.093
Strong – Feeble	r_s	0.104	-0.123	0.088
Quick Witted – Mentally Slow	r_s	-0.103	-0.126	-0.110
Proficient - Incompetent	r_s	0.012	-0.027	0.009
Interested - Bored	r_s	0.033	0.024	0.042
Sociable - Withdrawn	r_s	-0.025	0.054	-0.004
Friendly - Antagonistic	r_s	0.066	0.082	0.078
Happy - Sad	r_s	0.054	0.136	0.077
Calm – Excited	r_s	0.124	0.016	0.121
Tranquil - Troubled	r_s	0.084	-0.053	0.069
Contented - Discontented	r_s	0.060	0.025	0.068
Relaxed - Tense	r_s	0.109	0.120	0.125
N=129 for all correlations				
*** Correlation is significant at the 0.01 level*				
** Correlation is significant at the 0.05 level*				

Appendix 7 J Correlations between errors, overall mood and hunger

		E1	E2	E
Hungry - Full	r_s	-0.144	-0.157	-0.162
Best Mood –Worst Mood	r_s	0.050	0.081	0.074
N=129 for all correlations				
*** Correlation is significant at the 0.01 level*				
** Correlation is significant at the 0.05 level*				

Appendix 7 K Correlations between Bond Lader mood assessment and consistency of performance (FR)

		FR
Alert – Drowsy	r_s	0.039
Energetic – Lethargic	r_s	0.064
Clearheaded – Muzzy	r_s	-0.088
Well Co-ordinated - Clumsy	r_s	0.042
Strong – Feeble	r_s	0.096
Attentive - Dreamy	r_s	0.028
Quick Witted – Mentally Slow	r_s	-0.016
Proficient - Incompetent	r_s	0.031
Interested - Bored	r_s	0.069
Sociable - Withdrawn	r_s	-0.055
Friendly - Antagonistic	r_s	0.001
Happy - Sad	r_s	-0.041
Calm – Excited	r_s	0.074
Tranquil - Troubled	r_s	-0.038
Contented - Discontented	r_s	-0.008
Relaxed - Tense	r_s	0.014
N=129 for all correlations		
*** Correlation is significant at the 0.01 level*		
** Correlation is significant at the 0.05 level*		

Appendix 7 L Correlations between mood and consistency of performance

		FR
Hungry - Full	r_s	**-.094**
Best Mood –Worst Mood	r_s	-.049
N=129 for all correlations		
*** Correlation is significant at the 0.01 level*		
** Correlation is significant at the 0.05 level*		

Appendix 7 M Correlations (r_s) between Bond Lader Assessment and Word Fluency

		WF1	**WF2**	**WF3**
Alert – Drowsy	r_s	-0.087	-0.079	-0.018
Energetic – Lethargic	r_s	-0.062	-0.097	-0.083
Clearheaded – Muzzy	r_s	-0.034	0.033	-0.118
Well Co-ordinated - Clumsy	r_s	-0.027	0.003	0.030
Strong – Feeble	r_s	-0.158	0.015	0.021
Attentive - Dreamy	r_s	-0.060	-0.049	-0.103
Quick Witted – Mentally Slow	r_s	0.045	0.060	0.014
Proficient - Incompetent	r_s	-0.108	-0.043	-0.061
Interested - Bored	r_s	-0.154	-0.016	-0.102
Sociable - Withdrawn	r_s	-0.055	-0.063	-0.122
Friendly - Antagonistic	r_s	-0.125	-0.049	-0.075
Happy - Sad	r_s	-0.023	-0.068	0.035
Tranquil - Troubled	r_s	-0.045	-0.082	-0.026
Contented - Discontented	r_s	-0.087	-0.116	-0.037
Relaxed - Tense	r_s	-0.097	-0.067	-0.045
*** Correlation is significant at the 0.01 level*				
** Correlation is significant at the 0.05 level*				